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MINIMALITY AND MEMORY IN SYNTACTIC COMPLEXITY:
AN EMPIRICAL INVESTIGATION INTO THE PROCESSING OF RELATIVE CLAUSES AND CONTROL STRUCTURES

João Pedro Consciência Delgado

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João Pedro Consciência Delgado
Dissertação orientada pela Professora Doutora Ana Luísa Raposo
e coorientada pela Professora Doutora Ana Lúcia Santos

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Abstract

Object relative clauses (OR) are harder to process than subject relative clauses (SR). The complexity of OR has been attributed to intervention of the subject determiner phrase (DP) in the filler-gap dependency, either due to memory decay or interference, or as a consequence of grammatical restrictions on syntactic movement, based on Relativized Minimality (RM).

Subject control (SC) structures with ditransitive verbs, but not object control structures (OC), parallel OR in instantiating a filler-gap dependency across an intervening DP. Therefore, it is a question of interest whether SC patterns like OR in terms of processing complexity. Memory accounts of OR complexity expect parallel complexity asymmetries between relative clauses and control structures, i.e. greater processing difficulty with OR and SC than with SR and OC, respectively. Adopting the RM account of OR complexity, on the other hand, parallel asymmetries are expected only if control structures, like relatives, are derived via movement.

In this study, 69 participants read sentences and answered comprehension questions in a self-paced reading task with moving-window display, comprising four experimental conditions: *SR*; *OR*; *SC*; *OC*. Furthermore, participants performed four supplementary tasks, serving as measures of resistance to interference, verbal knowledge, working memory capacity and lexical access ability.

The results from the reading task showed that, whereas OR were harder to process than SR, SC was not harder to process than OC, arguing against memory accounts of OR complexity and, adopting the RM account, a movement analysis of control. Furthermore, we found that, although resistance to interference, lexical knowledge and working memory capacity modulated certain aspects of the processing of sentences with relative clauses, OR complexity effects emerging in comprehension accuracy and reading times were not modulated by any of these processes. We thus conclude that OR complexity effects result from a functionally isolated grammatical process, based on RM.

Keywords: Relative clauses, control structures, intervention, minimality, working memory

Resumo

As orações relativas de objeto (RO) são mais difíceis de processar do que as orações relativas de sujeito (RS). A complexidade das RO tem sido atribuída à intervenção do sintagma determinante (SD) sujeito na dependência *filler-gap*, quer devido a decaimento ou interferência em memória, quer em consequência de restrições gramaticais no movimento sintático, baseadas no princípio *Relativized Minimality* (RM).

Tal como as RO, as estruturas de controlo de sujeito (CS) com verbos ditransitivos instanciam uma dependência *filler-gap* com cruzamento de um SD interveniente, o que não acontece nas estruturas de controlo de objeto (CO). Portanto, é importante perceber se o CS revela uma complexidade de processamento equivalente à das RO. As propostas de memória para a complexidade das RO esperam assimetrias de complexidade paralelas entre relativas e controlo, i.e. maior dificuldade de processamento com RO e CS do que com RS e CO, respetivamente. Adotando a proposta de análise gramatical (RM) para a complexidade das RO, por outro lado, esperam-se assimetrias paralelas entre relativas e controlo somente se as estruturas de controlo, tal como as relativas, forem derivadas através de movimento sintático.

No presente estudo, 69 participantes leram frases e responderam a perguntas de compreensão sobre essas frases numa tarefa de leitura automonitorada, em quatro condições experimentais: *RS*; *RO*; *CS*; *CO*. Para além da tarefa de leitura, os participantes completaram quatro tarefas suplementares, servindo de medidas de resistência à interferência, conhecimento lexical, capacidade de memória de trabalho e habilidade de acesso ao léxico.

Os resultados da tarefa de leitura mostraram que, enquanto as RO foram mais difíceis de processar do que as RS, o CS não foi mais difícil de processar do que o CO, o que vai contra as propostas de memória para a complexidade das RO e, adotando a proposta gramatical (RM), a análise de controlo como movimento. Além disso, mostrou-se que, apesar de certos aspetos do processamento de frases com orações relativas terem sido modulados pela resistência à interferência, o conhecimento lexical e a capacidade de memória de trabalho, os efeitos de complexidade das RO emergentes na precisão de resposta à questão de compreensão e nos tempos de leitura não foram modulados por nenhum destes processos. Assim, concluímos que os efeitos de complexidade das RO são resultado de um processo gramatical funcionalmente isolado, baseado no princípio RM.

Palavras-chave: Orações relativas, estruturas de controlo, intervenção, minimalidade, memória de trabalho

Resumo alargado

As orações relativas contêm uma posição sintática vazia, ou *gap*, cuja interpretação depende do seu antecedente, ou *filler*. Na gramática generativa, as dependências *filler-gap* em orações relativas são analisadas como instâncias de movimento sintático: assume-se que o *filler* é movido da posição argumental encaixada para uma posição superior onde é pronunciado, deixando uma cópia silenciosa na posição original. Enquanto nas relativas de sujeito (e.g. O músico que criticou o pintor) o movimento do *filler* parte da posição de sujeito da oração relativa, nas relativas de objeto (e.g. O músico que o pintor criticou) parte da posição de objeto da oração relativa. Esta diferença estrutural está associada a uma assimetria de complexidade no processamento: as orações relativas de objeto são mais difíceis de compreender do que as orações relativas de sujeito, ainda que compostas pelas mesmas palavras.

As orações relativas têm sido objeto de estudo intensivo na Psicolinguística e têm desempenhado um papel central na teorização sobre complexidade sintática. Vários modelos de complexidade recentes atribuem o custo de processamento das orações relativas de objeto à intervenção de certos constituintes na dependência *filler-gap*: quer referentes de discurso novos – *Dependency Locality Theory* (Gibson, 1998, 2000); quer sintagmas nominais semelhantes ao *filler* – modelos *cue-based parsing* (Lewis, Vasishth & Van Dyke, 2006); quer sintagmas nominais (mais precisamente, DPs) semelhantes ao *filler* e ocupando uma posição sintática que lhes confere o estatuto de potencial interveniente hierárquico (o *filler* c-comanda o interveniente e o interveniente c-commanda o *gap*) - modelos com base no princípio *Relativized Minimality* (Friedmann, Belleti & Rizzi, 2009; Costa, Grillo & Lobo, 2013; Rizzi, 2013). Portanto, é relevante saber se outras estruturas sintáticas que envolvem uma dependência *filler-gap* cruzando constituintes intervenientes induzem efeitos de complexidade idênticos aos das relativas de objeto.

Tal como nas relativas, a compreensão de estruturas de controlo requer resolução de uma dependência *filler-gap*, que é estabelecida entre um sintagma determinante antecedente (SD), ou elemento controlador, e a posição vazia de sujeito da oração encaixada. No controlo de sujeito (e.g. O músico prometeu ao pintor escrever), o elemento controlador é o sujeito da oração matriz, enquanto no controlo de objeto (e.g. O músico convenceu o pintor a escrever) o elemento controlador é o objeto da oração matriz. Dada esta diferença, as estruturas com controlo de sujeito, contrariamente às estruturas com controlo de objeto, instanciam uma dependência *filler-gap* numa configuração de intervenção, justificando a hipótese de que estruturas com controlo de sujeito possam implicar custos adicionais de processamento.

Tradicionalmente, a Gramática Generativa tem tratado o controlo como fundamentalmente distinto das orações relativas. Nas análises clássicas, propõe-se que as dependências *filler-gap* no controlo correspondem a uma relação obrigatória de correferência entre uma categoria vazia especial (PRO), que se assume ocupar a posição de sujeito da oração encaixada, e o SD antecedente (Chomsky, 1981). No entanto, Hornstein (1999) propôs recentemente uma análise de movimento para o controlo, aproximando o controlo das orações relativas.

As estruturas de controlo têm recebido cada vez mais atenção nos estudos de aquisição, em que se documenta um atraso na aquisição de controlo de sujeito com verbos ditransitivos (e.g. Agostinho, Santos & Duarte, 2018), mas têm sido negligenciadas na investigação Psicolinguística com adultos, pelo que ainda não é claro se a assimetria observável em termos de desenvolvimento corresponde a uma assimetria de custos de processamento observável na idade adulta.

Neste estudo, procurámos avaliar a validade empírica das predições resultantes de explicações gramaticais e de memória para os efeitos de intervenção com relativas de objeto, comparando o processamento de orações relativas com o processamento de estruturas de controlo. Especificamente, procurámos investigar se a assimetria prevista entre relativas de sujeito e relativas de objeto, com maior complexidade observável nas relativas de objeto, resultante da configuração de intervenção, tem um paralelo nas estruturas de controlo, esperando-se nesse caso uma maior dificuldade associada a estruturas de controlo de sujeito. As explicações com base em questões de memória propõem que o efeito prejudicial da configuração de intervenção nas relativas de objeto resulta de princípios gerais da memória, como o decaimento (*Dependency Locality Theory*, Gibson, 2000) ou a interferência (*cue-based parsing*, Lewis, Vasishth & Van Dyke, 2006), que se aplicam de forma idêntica a estruturas de diferentes naturezas gramaticais. Aceitando as suposições dos modelos de memória, espera-se que as orações relativas e as estruturas de controlo revelem assimetrias de processamento paralelas. As explicações gramaticais, por outro lado, atribuem os efeitos de intervenção (neste quadro, intervenção é definida hierarquicamente) nas relativas de objeto ao princípio gramatical *Relativized Minimality*, que restringe a operação de movimento sintático quando há cruzamento de intervenientes (hierárquicos/sintáticos) (Friedmann, Belleti & Rizzi, 2009; Costa, Grillo & Lobo, 2013). Nesta abordagem, as previsões para o controlo dependem da sua natureza gramatical. Adotando a análise de movimento de Hornstein (1999), espera-se que as estruturas com controlo de sujeito em verbos ditransitivos manifestem efeitos de intervenção paralelos aos que se encontram em relativas de objeto, e, portanto, esperam-se assimetrias paralelas entre relativas e controlo. No entanto, se controlo não for movimento, não se esperam efeitos de intervenção paralelos entre controlo de sujeito e relativas de objeto. De acordo com esta perspetiva, os dados de processamento podem informar o debate sobre a natureza sintática de controlo.

Procurámos, também, explorar se diferenças individuais nos efeitos de intervenção em relativas de objeto e eventuais efeitos de intervenção em controlo de sujeito se correlacionam com diferenças individuais no desempenho em tarefas de: (i) resistência à interferência e (ii) conhecimento verbal, que emergem como potenciais moduladores de efeitos de intervenção no modelo *cue-based parsing* (Lewis, Vasishth & Van Dyke, 2006); (iii) capacidade de memória de trabalho, que emerge como potencial modulador de efeitos de intervenção na *Dependency Locality Theory* (Gibson, 1998, 2000) e na proposta de Friedmann, Belleti e Rizzi (2009), baseda no princípio *Relativized Minimality*; (iv) habilidade de acesso ao léxico, que surge como potencial modulador de efeitos de intervenção na proposta de Costa, Grillo e Lobo (2013), baseada no princípio *Relativized Minimality*. É importante notar que esta investigação contribui para a discussão sobre a questão fundamental da modularidade do sistema de processamento sintático. Espera-se que diferenças individuais no processamento sintático de orações relativas e controlo se correlacionem com o desempenho em tarefas de resistência à interferência, conhecimento lexical, capacidade de memória de trabalho e habilidade de acesso ao léxico somente se os processos cognitivos subjacentes ao processamento sintático forem de domínio geral. Se, por outro lado, o sistema responsável pelo processamento sintático for um módulo cognitivo, i.e., um sistema funcionalmente encapsulado, como proposto por Caplan e Waters (1999), não se esperam correlações.

Sessenta e nove falantes nativos do Português Europeu leram frases e responderam a perguntas de compreensão (*probes*) sobre essas frases numa tarefa de leitura automonitorada, em quatro condições experimentais: *Relativas de sujeito*; *Relativas de objeto*; *Controlo de sujeito*; *Controlo de objeto*. Registou-se a precisão e o tempo de resposta às perguntas de compreensão, bem como os tempos de leitura em cada palavra. Além da tarefa de leitura, os participantes completaram quatro tarefas suplementares: tarefa Brown-Peterson, proporcionando uma medida de resistência à interferência; subteste de vocabulário (WAIS-III), como indicador do conhecimento lexical dos participantes; *Reading Span,* proporcionando uma medida de memória de trabalho; tarefa de fluência semântica, como medida de conhecimento lexical.

Os resultados da tarefa de leitura mostraram que a precisão de resposta a perguntas de compreensão foi significativamente mais baixa para relativas de objeto do que para relativas de sujeito. Em concordância com estes resultados, os tempos de resposta às perguntas de compreensão e os tempos de leitura foram significativamente mais altos para relativas de objeto do que para relativas de sujeito. Quanto às estruturas de controlo, não se verificaram diferenças entre controlo de sujeito e controlo de objeto na precisão de resposta, mas sim nos tempos de resposta à pergunta de compreensão e nos tempos de leitura, com tempos de resposta mais longos para controlo de objeto e tempos de leitura mais longos para controlo de sujeito.

De forma global, os resultados da tarefa de leitura indicam que relativas de objeto são mais difíceis de processar do que relativas de sujeito, mas que estruturas de controlo de sujeito não são mais difíceis de processar que estruturas de controlo de objeto. Portanto, os resultados são inconsistentes com os modelos de memória (*Dependency Locality Theory* e *cue-based parsing*) e, assumindo-se uma abordagem gramatical de intervenção (*Relativized Minimality*), com a teoria de controlo como movimento, que preveem assimetrias paralelas entre orações relativas e estruturas de controlo. São, contudo, consistentes com a proposta de definição gramatical de efeitos de intervenção (*Relativized Minimality*) como base de uma explicação para a complexidade de orações relativas, se rejeitarmos a análise de controlo como movimento.

A análise de diferenças individuais na tarefa de leitura mostrou que a resistência à interferência e a capacidade de memória de trabalho modulam o processamento de frases com orações relativas e frases com controlo. Contudo, os efeitos de complexidade das relativas de objeto que se encontraram na tarefa de leitura só foram modulados pela capacidade de memória de trabalho, e apenas na medida de tempo de resposta à pergunta de compreensão.

Conclui-se que os tempos de resposta à pergunta de compreensão refletem processos diferentes daqueles de que dependem a precisão de resposta e os tempos de leitura e que os efeitos de complexidade das orações relativas têm origem num processo gramatical funcionalmente encapsulado, baseado no princípio *Relativized Minimality*.

"It is commonly believed that Newton showed that the world is a machine, following mechanical principles, and that we can therefore dismiss "the ghost in the machine," the mind, with appropriate ridicule. The facts are the opposite: Newton exorcised the machine, leaving the ghost intact."

Noam Chomsky

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1. Introduction

Headed relative clauses (see (1a) for a subject relative clause (SR) and (1b) for an object relative clause (OR)) contain an empty syntactic position, or gap (represented by the underscore), whose interpretation is dependent on the noun that they modify, or filler (i.e., *musician*).

(1) a. The musician$_i$ [that __$_i$ criticized the painter]

b. The musician$_i$ [that the painter criticized __$_i$]

In generative grammar, this filler-gap dependency is typically captured via the operation of syntactic movement: the filler is assumed to move from the empty position to the higher, surface position, leaving behind a silent copy. Relative clauses differ in the position from which the filler is moved. Whereas in SR the filler moves from the embedded subject position, in OR the filler moves from the embedded object position. Interestingly, this structural difference is associated with a complexity asymmetry: OR are harder to comprehend than SR, even though OR and SR may be composed by the same words (Gordon & Lowder, 2012).

Relative clauses have been thoroughly studied in Psycholinguistic research and have figured largely in many different theories of syntactic processing complexity. Recent theories have attributed the processing cost of OR to the intervention of certain constituents in the filler-gap dependency: either new discourse referents (i.e., *painter* and the event associated with the verb *criticized*) – Dependency Locality Theory (Gibson, 1998, 2000) - or phrases similar to the filler (i.e. *painter*) - cue-based parsing account (Lewis, Vasishth & Van Dyke, 2006) and Relativized Minimality approach (Friedmann, Belleti & Rizzi, 2009; Costa, Grillo & Lobo, 2013). Therefore, it is a question of interest whether other structures that also instantiate a filler-gap dependency in a relevant configuration of intervention (i.e., crossing new discourse referents or phrases similar to the filler) induce identical complexity effects.

Here, we explore this question in relation to control structures with ditransitive verbs. Comprehension of control structures (see (2a) for a subject control structure (SC) and (2b) for an object control structure (OC)) involves resolving a filler-gap dependency between an antecedent determiner phrase (DP), or controller, and an empty subject position (represented by an underscore) in the embedded clause.

(2) a. The musician$_i$ promised the painter [__$_i$ to write]

b. The musician forced the painter$_i$ [__$_i$ to write]

In SC, the controller is the matrix subject (i.e., *the musician*), whereas in OC it is the matrix object (i.e., *the painter*). Crucially, in SC (2a), but not in OC, there is a DP intervening in the filler-gap dependency, thus raising the question of whether SC induces complexity effects.

The grammatical nature of control structures is still in dispute. Traditionally, control structures have been treated as fundamentally distinct from structures involving movement; in a classic generative account, it is proposed that the filler-gap dependency in control should be captured by an obligatory coreference relationship between a special type of null category (PRO), assumed to fill the empty subject position, and the antecedent DP (Chomsky, 1981). However, recent work has proposed a movement analysis of control, on the grounds of parsimony, thus approximating control to relative clauses (Hornstein, 1999).

Control dependencies have received increased attention in the acquisition literature, wherein a delay of mastery of SC has been documented (e.g., Agostinho, Santos & Duarte, 2018), but they have been largely neglected in adult Psycholinguistic research. Thus, it is not yet clear whether adults find SC harder to process than OC.

Our first objective is to assess the empirical validity of predictions from memory and grammatical explanations of intervention effects in OR, and compare the processing of relative clauses with the processing of control structures, using a self-paced reading task. More specifically, we aim to assess whether the predicted comprehension asymmetry between SR and OR, with greater complexity in OR, as a result of intervention, is paralleled in control structures, with greater complexity in SC. Memory explanations propose that the pernicious effect of intervention in OR is due to general principles of memory, such as decay (Gibson, 1999, 2000) or interference (Lewis, Vasishth & Van Dyke, 2006), which ought to apply equally to structures of different grammatical natures, so long as the way in which grammar is implemented in memory does not differ. Adopting this framework, relative clauses and control structures are expected to reveal parallel asymmetries. Grammatical explanations, on the other hand, propose that intervention effects (wherein intervention is defined hierarchically) in OR result from an independently motivated grammatical principle termed *Relativized Minimality*, which limits syntactic movement across (hierarchical) interveners (Friedmann, Belleti & Rizzi, 2009; Costa, Grillo & Lobo, 2013). Within this framework, predictions for control depend on its grammatical nature. If a movement analysis of control is adopted, intervention effects of SC may be expected to parallel those of OR, and parallel asymmetries between relative clauses and control could thus be expected on the basis of Relativized Minimality. However, if control is not movement, as has been traditionally assumed, no parallel intervention effects between SC and OR are expected on the basis of Relativized Minimality. From this perspective, data from processing may bear on theoretical analysis of control.

Our second objective is to explore the predictions of memory and grammatical explanations of intervention effects for individual differences in processing of relative clauses and control. Specifically, we aim to assess whether individual differences in intervention effects of OR and potential intervention effects of SC are associated with individual differences in performance on tasks measuring i) resistance to interference and ii) verbal knowledge, which are expected to modulate intervention effects if the cue-based parsing memory account is assumed; iii) working memory capacity, which is expected to modulate intervention effects if the Dependency Locality Theory memory account or Friedmann, Belleti and Rizzi's (2009) grammatical account are assumed; and iv) lexical access ability, which should modulate intervention effects according to Costa, Grillo and Lobo's (2013) grammatical account. Crucially, this investigation touches on the question of modularity of the system for syntactic processing. Individual differences in the syntactic processing of relative clauses and control structures are expected to correlate with performance on tasks assessing resistance to interference, verbal knowledge, working memory capacity and lexical access abilities only if the cognitive processes underlying syntactic processing are influenced by domain-general mechanisms. If, on the other hand, the system responsible for syntactic processing is a cognitive module, i.e., a functionally isolated system, as has been proposed (Caplan & Waters, 1999), no such correlations are expected.

This thesis is organized in the following manner: in this chapter, we review relevant literature on the grammar and processing of relative clauses and control structures and provide a synthesis of the memory and grammatical models which attribute the well-established complexity effects of OR to intervention; in Chapter 2, we describe the experimental tasks and the statistical treatment of the experimental data; in Chapter 3, we present the experimental data and the statistical results; and, finally, in Chapter 4, we discuss our results in light of the literature reviewed in Chapter 1.

1.1. Subject relative clauses vs object relative clauses

In mainstream generative grammar, relative clauses (3, enclosed in brackets) are analyzed as instances of syntactic movement. Under current approaches to that-relatives, which are defined along the lines of Kayne (1994), it is assumed that the head noun of the relative clause (i.e., *musician*) moves from the embedded argument position to a higher, non-argument position, leaving behind a silent copy (represented by <*musician*> in 3), in what consists of a raising analysis of headed relatives – here I deliberately avoid the question of determining whether the moved element is an NP (noun phrase) or a DP (see the summary in Bianchi, 2002). Thus, even though the moved constituent is only verbalized once (in the higher position), it occurs twice in the mental representation of the sentence, allowing it to be simultaneously interpreted as the head of the relative and as an argument of the embedded verb (i.e., *criticized*).

(3) a. The musician [that <musician> criticized the painter] wrote a book.

b. The musician [that the painter criticized <musician>] wrote a book.

SR and OR differ as to the position from which movement takes place. Whereas the head noun moves from the embedded subject position in SR, it moves from the embedded object position in OR. This structural difference is associated with a complexity asymmetry: sentences containing OR (3b) are harder to process than sentences containing SR (3a). The asymmetry holds across different paradigms and measures, including: reading times and comprehension accuracy in self-paced reading tasks (e.g., King & Just, 1991; Gordon, Hendrick & Johnson, 2001; Grodner & Gibson, 2005; for European Portuguese, Costa, Grillo & Lobo, 2013), reading times in eye-tracking (e.g., Holmes & O'Regan, 1981; Traxler, Morris & Seely, 2002; Traxler, Williams, Blozis & Morris, 2005; Traxler et al., 2012), reaction times in phoneme-monitoring tasks (Frauenfelder, Segui & Meller, 1980), and reaction times in continuous lexical-decision tasks (Ford, 1983). Furthermore, compared to SR, the processing of OR stabilizes later in development (e.g., Friedman, Belleti & Rizzi, 2009; for European Portuguese, Costa, Lobo & Silva, 2011), is associated with greater activation in Broca's area (inferior frontal cortex) and Wernicke's area (lateral superior temporal cortex), which have been associated with language processing, notably, syntactic complexity (Just, Carpenter, Keller, Eddy & Thulborn, 1996, see Friederici, 2011 for a review), and is impaired in patients with agrammatic Broca's aphasia (Grodzinsky, 2000; Garrafa & Grillo, 2008).

In reading tasks, the contrast between sentences containing SR and OR is usually found both online and offline, with longer reading times for sentences containing OR often co-occurring with lower accuracy in answering comprehension probe questions, suggesting that comprehension difficulty stems from early stages of processing and is hard to overcome. Grodner and Gibson (2005) attempted to pinpoint precisely the locus of parsing complexity of sentences containing OR, by asking participants to read sentences containing SR and OR, such as those in (4a) and (4b), respectively, in a word-by-word self-paced reading task.

(4) a. The reporter [who sent the photographer to the editor] hoped for a story.

b. The reporter [who the photographer sent to the editor] hoped for a story.

(Grodner & Gibson, 2005: 266)

Reading times at the whole embedded relative clause region (enclosed in brackets) were significantly longer for the OR condition (4b) than for the SR condition (4a). Since this region contains the exact same words in both conditions, only in a different order, the significant difference may be safely attributed to processing differences related to subject and object gap filling. The comparison of the constituents inside the relative clause region revealed a significant difference at the embedded verb (i.e., *sent*), with longer reading times for the OR condition, but no differences at the relative pronoun (i.e., *who*) or at the embedded DP (i.e., *the photographer*). Each of these three comparisons is hard to interpret by itself, since the constituents inside the relative clause occur in different positions in SR and OR, and position is known to affect reading times; however, together, they suggest that processing complexity of OR is driven by difficulty at the embedded verb site. Grodner and Gibson (2005) also found a significant difference in the prepositional phrase that followed the gap in OR / the direct object in SR (i.e., *to the editor*), with longer times for OR than for SR. Since this region is identical in SR and OR, the significant difference suggests that difficulty with gap-filling in OR persists in subsequent regions (as is well known to happen in self-paced reading tasks, wherein effects of a given region often "spill" to subsequent regions, termed *spillover regions*, Just, Carpenter & Woolley, 1982). Finally, no differences were found at the main verb region (i.e., *hoped*), indicating that difficulty with sentences containing OR is dependent on the relative clause only, and not on an interaction between the relative clause and the main verb.

King and Just (1991) and Gordon, Hendrick and Johnson (2001), among others, have reported reading time patterns generally consistent with the analyses of Grodner and Gibson (2005), with longer reading times for OR than SR typically surfacing at the embedded verb region and/or the spillover region (usually a main verb, like in 3).

1.2. Subject control vs. object control

Obligatory control refers to an interpretive dependency between a null subject of an embedded infinitival clause (the most common case) and a specific argument of the matrix clause. Since the matrix argument determines the interpretation of the embedded subject, the latter is said to be controlled by the former. Obligatory control structures may involve ditransitive control verbs, i.e., verbs that select two internal arguments (i.e., *the painter* and the embedded infinitival clause containing a controlled null-subject, in 5). In sentence (5a), the null subject is interpreted as controlled by the subject of the matrix clause, *the musician*, entailing SC. In sentence (5b), on the other hand, the null subject is interpreted as controlled by the object of the matrix clause, *the painter*, entailing OC. In these structures, the choice of controller depends on the matrix verb: verbs like *promise* produce SC structures, whereas verbs like *convince* produce OC sentences. Hence, correct interpretation of control is determined by (matrix) verb meaning.

(5) a. The musician$_i$ promised the painter [__$_i$ to write a book]

b. The musician convinced the painter$_i$ [__$_i$ to write a book]

Despite superficially similar to structures assumed to be derived via movement (e.g., subject and object raising, passives), obligatory control dependencies have been treated differently in mainstream generative grammar. It is generally assumed that obligatory control involves a dependency between a special type of null element in the subject position of the embedded clause, termed *PRO*, and an antecedent located in the matrix clause (Chomsky, 1981).

Stipulation of PRO is a theoretical last resort maneuver justified by a derivational principle called the *theta-criterion*, which requires the arguments of a sentence to be in a one-to-one match configuration with the theta-roles assigned by the predicates of the sentence. The theta-criterion correctly predicts that sentences such as (6) are ungrammatical, since the predicate *love* cannot assign its two theta roles to *John*; if it were not for the theta-criterion, *John* should be able to merge with *love* in the object position and then move to the subject position, functioning both as subject and object of *love*.

(6) *John loves very much. (Meaning: John loves himself very much)

By the same token, the theta-criterion prohibits a movement derivation of control, since the element to be moved (e.g., *the musician* in (5a)) would be assigned two theta-roles (i.e., one by the verb *write* and one by the verb *promise*). Under an analysis that postulates the existence of PRO, on the other hand, only one theta role is assigned to each constituent – one to PRO, by the embedded verb, and one to its antecedent, by the matrix verb – conforming with the theta-criterion.

Recently, however, some theoreticians have argued for a movement analysis of control, on the grounds of parsimony (Hornstein, 1999; Boeckx, Hornstein & Nunes, 2010). Under this analysis, it is assumed that *the musician* moves from the embedded subject position to the matrix subject position in (5a), allowing it to be interpreted as subject of both *write* and *promise*, and that *the painter* moves from the embedded subject position to the matrix object position in (5b), allowing it to be interpreted as subject of *write* and object of *convince*. In short, PRO is dispensed with, the theta-criterion is abandoned and the work done by the theta-criterion is delegated to other components of the grammar (for critiques of the movement theory of control, see Culicover & Jackendoff, 2001 and Landau, 2003).

Control structures have received considerably less attention in psycholinguistic research than relative clauses. Therefore, it is still not clear whether the structural difference between SC and OC is associated with a processing asymmetry, although the existing evidence suggests a positive answer. Acquisition studies reveal a robust asymmetry parallel to that of relative clauses, with subject control, i.e., the structure with the filler-gap dependency crossing intervening material, stabilizing later in development than object control (Chomsky, 1969; Mateu, 2016; for European Portuguese, Agostinho, Santos, Duarte, 2018). These data could justify the hypothesis that the same complexity constraints may be operative in relative clauses and control structures (but see Martins, Santos & Duarte, 2018 for evidence that the developmental course may differ between the two syntactic structure types). Studies with adults point in the same direction, although the evidence is scarce[1]. Betancort, Carreiras and Acuña-Fariña's (2006) compared processing of SC and OC structures with ditransitive verbs in Spanish using eye-tracking (see (7) for a sample of the materials used[2]).

(7) a. María$_i$ prometió a Pedro PRO$_i$ ser bastante cauta con los comentarios

'Mary$_i$ promised Peter PRO$_i$ to be quite cautious with her comments'

b. María exigió a Pedro$_i$ PRO$_i$ ser bastante cauto con los comentarios

'Mary demanded from Peter$_i$ PRO$_i$ to be quite cautious with his comments'

(Betancort, Carreiras & Acuña-Fariña, 2006: 228)

Results showed slower reading times for SC than OC structures at the complement preceding the empty position (i.e., *a Pedro*), both in early (first-pass reading times) and late reading measures (regression path times and total reading times). Assuming, as Betancort, Carreiras and Acuña-Fariña (2006) suggest, that this difference may have reflected parafoveal processing of the subsequent region (containing the empty position), we can interpret these results as suggestive that: i) The control dependency is resolved in the first region in which there is unambiguous evidence for the existence of an empty position, i.e., information about the control verb is accessed and used to determine the filler of the empty position as soon as the first region manifesting the lack of a constituent is processed; ii) Resolution of the control dependency is more demanding for SC than for OC. However, we should note that the length

[1] Most studies involving processing of control structures in adulthood focused on different questions, such as whether control information is delayed in parsing, e.g., Frazier, Clifton & Randall (1983); Boland, Tanenhaus & Garnsey (1990). Although potentially informative as to whether subject and object control differ in complexity, these studies yielded conflicting results and, importantly, involved complex interactions between control and wh-dependencies, complicating interpretation of the results.
[2] Although agreement match was also manipulated, we will focus only on grammatical sentences, as data from processing of agreement does not bear on our questions. The effects of agreement match did not interact with the effects of control structure.

of the region preceding the empty position (i.e. the length of the complement preceding the complement clause) differed between SC and OC in several items and that statistical control for length was only reported for the analyses of the early reading measures, casting doubt on whether the results obtained with the late reading measures are reliable. Furthermore, even though there were no significant comprehension accuracy differences between conditions, the comprehension probes were presented for only one third of the trials and are not described in the paper, precluding conclusions about late stages of comprehension of control structures.

A recent study provided converging evidence that control dependencies crossing intervening material are more demanding than control dependencies that are established locally. Kwon and Sturt (2016) had participants read sentences with nominal giver control (8a) and nominal recipient control (8b) in an eye-tracking setting[3].

(8) a. Naturally, Luke$_i$'s promise to Sophia PRO$_i$ to photograph himself in the barn amused everyone.

b. Naturally, Luke's plea to Sophia$_i$ PRO$_i$ to photograph herself in the barn amused everyone.

(Kwon & Sturt, 2016)

A significant difference in a late reading measure (first-pass regressions out) was found at the region containing *to* and the infinitival verb (i.e., *photograph*), with more regressions in sentences with nominal giver control than in sentences with nominal recipient control. Although these data were obtained with control in nominal structures instead of control in complements of verbs, the parallel results – longer reading times for sentences containing

[3] Agreement match was also manipulated, but details concerning this manipulation will be omitted, since they are not relevant for our current purposes. Agreement match did not interfere with effects of control structure.

control dependencies across intervening constituents – suggest that the association between intervention in the filler-gap dependency and long reading times in control is robust. As in the study of Betancort, Carreiras and Acuña--Fariña (2006), however, conclusions about later stages of comprehension of control structures are precluded by lack of information about the offline comprehension component of the task.

In sum, data on processing of control structures, though scarce, are indicative of a complexity asymmetry parallel to that of relative clauses, i.e., more difficulty in SC than in OC. However, we stress that the lack of data on offline comprehension of control structures significantly limits these conclusions.

1.3 Capacity Models

1.3.1 Memory capacity and the Dependency Locality Theory

Memory capacity limitation accounts of syntactic complexity phenomena have been very influential in cognitive science research. Part of the reason for this is that capacity accounts are intuitive. Consider the structure in (9), containing an infamous double center-embedding (represented with brackets – each embedding consists of an OR).

(9) The musician [that the painter [that the doctor met] criticized] wrote a book.

This structure is considered unacceptable by most speakers. Yet, there is no reason to assume that it is ungrammatical, since it can be obtained from the acceptable structure in (10) by recursively applying the syntactic rule that produces the object relative clause.

(10) The musician [that the painter criticized] wrote a book.

This was long taken to suggest that the cause of parsing breakdown in structures like (9) is to be found in processing constraints (Chomsky & Miller, 1963). Assuming that our working memory (i.e., memory for temporarily maintaining and storing information, supporting human thought processes, Baddeley, 2003) is limited in capacity, processing of (9) is expected to break down due to memory loss, e.g., if we do not have sufficient capacity to maintain *the musician* in memory until it is integrated as object of *criticized* and the DP it is part of is integrated as the subject of *wrote*, comprehension is expected to suffer.

Although the specificities of what is assumed to be maintained in memory and how memory may be constrained vary (Gibson, 1998; Just and Carpenter, 1992; Wagers & Phillips, 2014), capacity models share the fundamental assumption that the human working memory system has limited resources for sentence parsing. In a very influential article, Just and Carpenter (1992) proposed that the working memory system for language comprehension is a computational device responsible for both storage and manipulation of sentence elements. In this model, storing elements, as well as performing attachments and other computations related to syntactic and semantic structure building, consumes resources, or activation. Since activation is limited, only a restricted number of elements may be stored and/or acted on at each time. Furthermore, storage and processing trade-off, in the sense that more demanding computational processes leave less activation for storing, and vice-versa. These ideas directly influenced Gibson's (1998, 2000) Dependency Locality Theory (DLT), which we will consider in more detail, since it makes fine-grained, generalizable predictions of complexity based on a few principles of memory cost.

In his exposition of the theory, Gibson (1998, 2000) assumes a theoretically neutral phrase-structure grammar (see Figure 1), though it is noted that the theory is compatible with a wide range of phrase-structure theories, including the Minimalist program (Chomsky, 1995). In what follows, we review Gibsons' theory following his assumption.

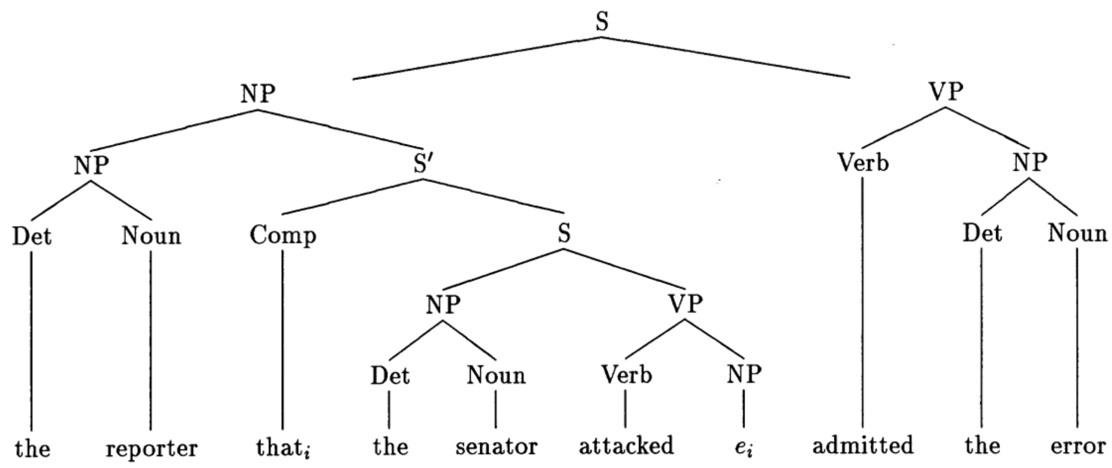

Figure 1. Representation of the tree structure assumed to underly the sentence *The reporter that the senator attacked admitted* the error in Gibson, 1998, 2000 (taken from Gibson, 1998: 14).

Gibson's DLT is fundamentally a metric of moment to moment (i.e., word by word) sentence complexity. Following Just and Carpenter (1992), he assumes that there are two components of parsing that interact to determine complexity in sentence processing: (i) performing structural integrations, i.e., connecting each new word to the syntactic and discourse structure built thus far; (ii) and keeping sentence elements in memory[4]. Whereas the storage component is assumed to be invariant of distance, the integration component is assumed to critically depend on distance (or locality, in Gibson's terms), so that, other things equal, longer dependencies are expected to be more costly. More specifically, the cost of integration of a new word heading a syntactic projection (e.g., a verb, heading a VP) with a previously constructed projection (e.g., NP[5]) depends on the distance between that word and the head of the projection with which it is integrated (i.e., the head verb and the head noun, respectively). The motivation for this is that integration of a newly formed projection with a previous one headed by *X* requires reactivating aspects of *X* from memory, whose activation

[4] The structure built thus far, as well as predictions of upcoming elements.
[5] In the Minimalist program, it would be a DP.

presumably decays with distance.[6] Importantly, distance is not equated with time. Rather, it is the complexity of the material that (linearly) intervenes between the heads of the projections being integrated (e.g., NP and VP) that determines processing difficulty. If processing the intervening material requires more resources than the individual has available, the antecedent head (e.g., noun) can no longer be retained and decays, requiring a costly reactivation process at the moment at which its projection is integrated with the projection of the dependent head (e.g., verb), and comprehension is expected to decay.

In DLT, the complexity of intervening material is operationalized as the number of intervening new discourse referents, i.e., entities that have a spatiotemporal location so that they can be recovered by an anaphoric expression. These entities are introduced by noun phrases that refer to a new discourse object and a VP that refers to a new discourse event[7]. Therefore, processing the head noun of an NP and processing the head of a VP are assumed to be responsible for the bulk of computational load related to sentence structure building. Evidence for the validity of this assumption comes from contrasts such as that in (11).

(11) a. The musician that the painter that the doctor met criticized wrote a book

b. The musician that the painter that I/you met criticized wrote a book

As first noted by Bever (1970), the structures with double center-embeddings in which the most embedded subject is an indexical pronoun, the first- or second-person pronoun in (11b), seem to be more acceptable than structures with double center-embeddings in which all

[6] It is assumed that when a syntactic head, e.g., a noun, is processed, the parser represents lexically-based predictions of possible upcoming dependent elements, e.g., a verb (since at least a verb is necessary to entail a grammatical sentence). When the dependent element is processed, it is matched with the syntactic prediction, which reactivates the lexical head associated with the prediction, so that the plausibility of the head-dependent relationship can be evaluated within the discourse context.

[7] Gibson notes that the complexity of the integrations required by the intervening elements should also enter in the equation of complexity. However, we will ignore these additional costs, following Gibson, since a simplified metric is sufficient to predict complexity contrasts under most circumstances.

embedded subjects are descriptions (11a). A questionnaire study by Gibson and Warren (1998) (cited in Gibson, 1998) provided support for this intuition. As expected, sentences containing embedded indexical pronouns were rated as easier to understand than sentences containing descriptions. Furthermore, this difference disappeared when a third-person pronoun was used, suggesting that the facilitatory effect associated with indexical pronouns is due to them not introducing new discourse referents in the discourse structure (which is expected to always include a speaker/writer and a listener/reader). Under DLT, we can therefore say that (11b) is easier to process than (11a) because, from a complexity perspective, one less discourse referent intervenes in the relationships established between *musician* and the verbs *criticized* (when the NP headed by *musician*[8] is co-indexed with an empty category in the object position of *criticized*) and *wrote* (when the NP headed by *musician* is integrated as subject of *wrote*). The same applies to the dependencies established between *painter* and the verbs *met* (when the NP headed by *painter* is co-indexed with an empty category at the object position of *met*) and *criticized* (when the NP headed by *painter* is integrated as subject of *criticized*).

The DLT predicts several processing complexity contrasts (see Gibson, 1998 for a review). One of the contrasts correctly predicted by the DLT is the well-established asymmetry between sentences containing SR and OR (like in 1, repeated in 12 for convenience), which we shall now derive as an example. We will consider integration costs alone, which, though likely to interact with storage costs, provide a good approximation of complexity when storage costs aren't too severe (Gibson, 2000)[9]. We will discuss only integrations of NPs with verbs and empty categories.[10]

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[8] As noted, Gibson adopts a theoretically independent phrase-structure grammar. Hence, it is assumed that *the musician* is an NP headed by the noun *musician*, constituting the logical object of *criticize*. Similarly, the matrix subject *the musician who the painter who the doctor met criticized* is assumed to be an NP headed by the noun *musician*.

[9] Since SR and OR contain the same discourse referents, we will also ignore the cost associated with constructing each new discourse referent, which is the same in SR and OR.

[10] Other integrations, such as those between determiners and nouns, are omitted, since they are local and do not differ between SR and OR.

A linear relationship between the number of intervening new discourse referents and integration cost is assumed, such that each new discourse referent incurs a cost of one energy unit (EU).

(12) a. The musician$_i$ [that __$_i$ criticized the painter] wrote a book

b. The musician$_i$ [that the painter criticized __$_i$] wrote a book

In sentence (12a), containing a SR, the NP *the musician* is first co-indexed with the empty category assumed to fill the subject position of *criticized*. Since this integration is local, i.e., there is no intervening word introducing a new discourse referent between the head noun *musician* and the empty category, no significant cost is incurred. Then, the empty category is integrated as subject of the embedded verb *criticized*, in another local dependency with no cost. Next, *the painter* is attached as object of *criticized*, again, in a local dependency with no cost. The following integration, however, involves a crossing dependency: *the musician that criticized the painter* is attached as the subject of the verb *wrote*. Since three expressions introducing new discourse referents (i.e., *criticized*, *the painter* and *wrote*) were introduced since the head noun *musician* was seen, this integration incurs a cost of 3 EU. Finally, *a book* is integrated as object of *wrote*, with no cost. Now, let's take a look at sentence (12b). First, the embedded subject *the painter* is integrated with the embedded verb, with no cost. Then, *the musician* is co-indexed with the empty category at the embedded object position, with a cost of 2 EU, since two expressions introducing new discourse referents, *the painter* and *criticized*, were introduced since *musician* was seen. The empty category is then integrated as object of *criticized*, with no cost. Next, *the musician that the painter criticized* is attached as the subject of the verb *wrote*, with the cost of 3 EU, as in sentences containing SR. Finally, *a book* is integrated as object of *wrote*, with no cost. As we can see, the DLT attributes the contrast between sentences containing SR and OR to differential processing of the embedded verb, which is in line with the empirical data reviewed in section 1.1.

1.3.2. Individual differences in working memory capacity

The research on individual differences in linguistic behavior grew hand-in-hand with the capacity account of sentence comprehension. Daneman and Carpenter (1980), among others, proposed that all verbal tasks draw on the same working memory resources, which, in turn, vary from individual to individual. The larger the resource pool, or capacity, the better the performance on complex verbally mediated tasks. To test this hypothesis, Daneman and Carpenter (1980) developed a new task designed to measure working memory capacity (WMC) for language, termed the *Reading Span task*. In the original version, participants were required to read aloud sequences of sentences and to recall the final words of all sentences in each sequence, by order of occurrence. Sequence length increased throughout the experiment, and memory span was defined as the longest sequence at which participants could recall all sentence-final words in the majority of trials.

The Reading Span task consisted of a modification of the traditional Word Span task, in which participants are presented with increasingly longer sequences of words that they then must recall. Importantly, since the Reading Span involved both storage (keeping words in memory) and processing (reading sentences) functions, Daneman and Carpenter (1980) argued that it was better suited to capture differences in working memory capacity than the Word Span, which, for lacking a processing component, was proposed to target short-term memory retention instead. In their view, Reading Span should correlate with language processing because individuals with more language aptitude would be able to process the sentence component of the Reading Span spending fewer resources, having more resources available for retention of the sentence-final words.[11] Consistent with this reasoning, the authors found that the Reading Span significantly correlated with language aptitude, as assessed by the Verbal Scholastic Aptitude Test (a standardized test used for college admissions in the US) and complex linguistic tasks involving retrieval of facts and pronoun antecedents from texts, whereas Word Span did not. These results were deemed important for two reasons: they showed that individual differences in linguistic behavior can be related to memory capacity; and they provided initial support for the construct validity of the Reading Span measure.

Following Daneman and Carpenter (1980), several other studies found Reading Span to be correlated with complex linguistic behavior (see Just and Carpenter, 1992 for a review). Most relevant to our purposes, King and Just (1991) demonstrated that Reading Span differentially predicted performance with sentences containing SR and sentences containing OR in a self-paced reading task. Whereas comprehension accuracy was generally worse for participants with low span than for participants with high span, the difference was accentuated in OR sentences. Similarly, low span participants were slower than high span participants at reading the demanding spillover region, but this effect increased in sentences containing OR. As noted by Caplan and Waters (1999), the critical interaction between Reading Span and sentence type directly supports the hypothesis that processing syntactically complex structures depends on working memory abilities. More specifically, larger differences between low and high spans in more complex sentences (OR) indicate that working memory is positively involved in syntactic processing, thus supporting the capacity account, since WMC is expected to be most relevant in contexts that are more resource demanding.

Despite promising, the results obtained by King and Just (1991) were soon found to be hard to replicate. Caplan and Waters (1999) reported several experiments in which no

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[11] Daneman and Carpenter believed that the verbal component in the Reading Span task was essential for it to correlate with sentence processing, since verbal tasks were assumed to draw on a pool of verbal memory resources. However, the same reasoning applies if we assume that sentence processing draws on more general memory resources.

interaction between Reading Span and relative clause type was observed. Furthermore, Caplan and Waters (1999) also reported evidence that (i) when participants had to memorize lists of digits while reading sentences (i.e., having an external memory load), sentence comprehension decreased in an equal magnitude with SR and OR; (ii) subjects with working memory deficits did not reveal larger effects of relative clause type than healthy subjects (Caplan & Waters, 1999). Caplan and Waters (1999) took these results as suggestive that the memory system responsible for syntactic analysis and extraction of meaning from sentences is a module, that is, a functionally isolated cognitive system. In this view, effects of syntactic complexity (e.g., SR vs. OR) and performance at memory tasks are not expected to interact.

The debate on the modularity of syntactic processes is far from being settled. Although some recent studies have provided evidence consistent with the modular account (e.g., Caplan & Waters, 2005; Caplan, Dede, Waters, Michaud & Tripodis, 2011; James, Fraundorf, Lee & Watson, 2018), others have provided results that point in a different direction (e.g., Gordon, Hendrick & Levine, 2002; Fedorenko, Gibson & Rhode, 2006; Fedorenko, , Woodbury & Gibson, 2013; Van Dyke, Johns & Kukona, 2014, Nicenboim, Vasishth, Gattei, Sigman & Kliegl, 2015; Tan, Martin & Van Dyke, 2017), including interactions between sentence complexity (syntactic dependency length) and complex span tasks, i.e., tasks that, like the Reading Span, interleave a processing and a storage component (e.g., Nicenboim, Vasishth, Gattei, Sigman & Kliegl, 2015), as predicted by capacity models. This is an important issue that taps into deep questions related to mind/brain architecture. Clearly, more research is needed. It is important to stress, however, that even though capacity models grew hand in hand with research on individual differences in sentence processing, with evidence for memory effects in parsing taken as evidence for capacity models, one does not need to endorse a non-modular view of language to accept a capacity explanation of sentence complexity. Even if the system for syntactic processing is modular, it is certainly constrained, as evidenced by the well-established difficulty in processing sentences containing OR.

1.4. Cue-based parsing models

1.4.1. Similarity-based interference in sentence processing

In recent years, memory constraints in sentence processing have been approached from a different angle. Similarity-based interference phenomena have been shown to be operative across different linguistic contexts. One of the most striking evidences for this came from a study by Gordon, Hendrick and Johnson (2001). Gordon and colleagues conducted a word-by-word self-paced reading experiment in which participants read sentences containing SR (13a) and OR (13b).

(13) a. The banker that praised the barber/Sue climbed the mountain.

b. The banker that the barber/Sue praised climbed the mountain.

(Gordon, Hendrick & Johnson, 2001: 1423)

Importantly, the type of NP2 was manipulated, such that NP2 could be either a description (i.e., *barber*) or a proper name (i.e., *Sue*). In line with previous studies, comprehension accuracy was higher for SR than OR sentences. However, this effect interacted with NP2 type: whereas there was a significant difference between SR and OR in sentences containing embedded descriptions, there was no difference in sentences containing proper names. Likewise, analysis of reading times at the main verb region (i.e., spillover region) revealed a significant interaction between relative clause type and NP2 type: reading times were longer for sentences containing OR than sentences containing SR when NP2 was a description, but not when it was a proper name. Another experiment showed that similar facilitatory effects in the processing of OR were also elicited when NP2 was the indexical pronoun *you* (Gordon, Hendrick & Johnson, 2001). Importantly, though facilitation with indexical pronouns is consistent with Gibson's DLT (Gibson, 2000), facilitation with proper names suggests a different locus for the effect, since proper names introduce new discourse referents. Gordon and colleagues attributed these results to similarity-based interference in memory between NP1 and NP2[12].

Similarity-based interference in sentence processing has been shown to depend on properties other than noun type and to occur in contexts other than resolution of filler-gap dependencies. Van Dyke (2007), for instance, investigated semantic and syntactic interference in the processing of *long-distance subject-verb dependencies*[13] - see (14) for a sample of the materials.

(14) a. The pilot remembered that the lady [who was sitting in the smelly seat yesterday afternoon] moaned about a refund for the ticket.

b. The pilot remembered that the lady [who was sitting near the smelly man yesterday afternoon] moaned about a refund for the ticket.

c. The pilot remembered that the lady [who said that the seat was smelly yesterday afternoon] moaned about a refund for the ticket.

d. The pilot remembered that the lady [who said that the man was smelly yesterday afternoon] moaned about a refund for the ticket.

(Van Dyke, 2007: 418)

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[12] See Gordon, Hendrick and Johnson (2004) for evidence that, more generally, common names interfere with each other, but not with other noun types, such as proper names, pronouns and quantified expressions, possibly because the former refer indirectly, via a description, whereas the latter may refer more directly: their semantic value may be provided extensionally.

[13] *Long-distance subject-verb dependencies* refers to contexts wherein the head noun of a subject is not adjacent to the verb with which the subject is integrated.

The target subject head noun (i.e., *lady*) was separated from the critical main verb (i.e., *moaned*) by the intervening material in brackets. Importantly, the syntactic similarity and semantic similarity of the noun embedded in the relative clause (i.e., *seat/man*) in relation to the target subject head noun were orthogonally manipulated. In sentence (14a), the intervening noun (i.e., *seat*) is semantically unfit for being an argument of the main verb and is part of a prepositional phrase (PP), therefore expected to be distinguished from the target on both syntactic and semantic grounds, since the target is semantically fit for being an argument of the main verb and is part of a subject. This sentence therefore implies low semantic and syntactic interference. In sentence (14b), the intervening noun (i.e., *man*) is semantically fit for being an argument of the main verb and is part of a PP, therefore distinguished from the target syntactically, but not semantically, implying low syntactic interference, but high semantic interference. In sentence (14c), the intervening noun (i.e., *seat*) is semantically unfit for being an argument of the main verb and is part of a subject, overlapping with the target subject head noun in the manipulated syntactic, but not semantic, properties, thus implying high syntactic interference, but low semantic interference. And, finally, in sentence (14d), the intervening noun (i.e., *man*) is semantically fit for being an argument of the main verb and is part of a subject, just like the target subject head noun, implying high syntactic and semantic interference. Participants read sentences like (14) in an eye-tracking setting. Comprehension accuracy was lower for sentences with high syntactic interference than for sentences with low syntactic interference and lower for sentences with high semantic interference than for sentences with low semantic interference. As for reading times, analysis of the critical main verb region (i.e., *moaned*) revealed that high syntactic interference resulted in longer times, both in early reading measures (first-pass reading times) and late reading measures (regression path time). Interestingly, the effect of syntactic interference was significant considering only sentences with low semantic interference (i.e., sentence 14a vs sentence 14c), indicating that a syntactic distractor, even when semantically implausible, may be considered as a potential target (head noun) in the subject-verb dependency. Analysis of the final region (i.e., *for the ticket*), on the other hand, revealed longer reading times for sentences with high semantic interference than low semantic interference in a late reading measure (regression path time). Analogously to the effect of syntactic interference found at the main verb, the effect of semantic interference was found considering only the sentences in which the distractor was not syntactically appropriate (i.e., sentence 14a vs 14b). In sum, these results suggest that both syntactic and semantic similarity between nouns in a sentence may interfere, independently of one another, with resolution of the subject-verb dependencies.

Using a memory load paradigm, Van Dyke and McElree (2006) provided evidence that even fine-grained semantic cues may cause interference effects. Participants read object clefts such as (15) in a phrase-by-phrase self-paced fashion (bars indicate how regions were segmented for presentation).

(15) a. It was the boat/ that the guy/ who lived/ by the sea/ sailed/ in two sunny days

b. It was the boat/ that the guy/ who lived/ by the sea/ fixed/ in two sunny days

(Van Dyke & McElree, 2006: 160)

In object clefts, like in OR, there is a displaced object (i.e., *the boat*) that needs to be integrated with an empty position at the verb site (i.e., *sailed/fixed*). This filler-gap dependency was the target dependency assessed. The study included *no load* conditions, in which participants only read sentences for comprehension, as well as *load* conditions, in which, additionally, participants were presented with three words (e.g., *table*, *sink*, *truck*) before reading the sentence and were asked to recall those words after reading the sentence. Importantly, the critical verbs could be either interfering verbs, such as *fixed* (sentence 15b), i.e., verbs for which the memory load words were semantically plausible potential objects (they are fixable things), or non-interfering verbs, such as *sailed* (sentence 15a), i.e., verbs for which the memory load words were semantically implausible potential objects (they are not sailable things). Reading times at the critical verbs were longer for interfering than for non-interfering verbs. Crucially, this difference was only significant in the load conditions, suggesting that the memory load words, when semantically compatible with the verb, cause interference at integration of the target object.

These results were taken to indicate not only that similarity-based interference modulates syntactic processing, but also that the memory system subserving sentence comprehension is not functionally isolated, contra Caplan and Waters (1999), since a concurrent memory task interfered with syntactic parsing (see Gordon, Hendrick & Johnson, 2002, for similar results with clefts; Fedorenko, Gibson & Rohde, 2006, for similar results with relative clauses). An intriguing possibility, then, is that previous studies failing to reveal interactions between sentence complexity effects and external memory loads (Caplan and Waters, 1999) may simply have used the wrong material. The similarity-based approach proposes that it is the quality, more than the quantity, of the material in memory that determines interference. Since Caplan and Waters (1999) used digits for load material, which are qualitatively different from the nouns used in the sentences, the null results are expected, as are the null results obtained in Van Dyke and McElree (2006) with a memory load of words that were semantically different from the words used in the sentence.

In sum, it is now generally assumed that similarity-based interference is a property of the memory system for parsing (see Jager, Engelman & Vasishth, 2017 for a review), showing up not just in the processing of filler-gap dependencies (e.g., relative clauses) and subject-verb dependencies, but also in agreement dependencies (Wagers, Lau & Phillips, 2009; Dillon, Mishler, Slogget & Phillips, 2013), negative polarity items (Vasishth, Brussow, Lewis &

Drenhaus, 2008) and antecedent-reflexive dependencies (Jager, Mertzen, Van Dyke & Vasishth, 2019; but see Dillon, Mishler, Sloggett & Phillips, 2013 and Dillon, 2014). What counts as "similar" is a topic of very active research, but it's clear that a wide variety of linguistic properties (i.e., syntactic, semantic, referential type) may contribute.

1.4.2. Content-addressable retrieval

Interference effects in sentence processing are reminiscent of well documented interference effects in memory research (Nairne, 2002, Anderson, 2003). A good illustration of this comes from studies with the Brown-Peterson paradigm (Brown, 1958, Peterson & Peterson, 1959, Watkins & Watkins, 1975). In this paradigm, participants read lists of items (e.g., words), one at a time, that they ought to memorize. After reading a list, participants perform a distractor task, aimed at preventing rehearsal, and then they attempt to retrieve the items of the list they just saw. Interestingly, performance with a given list of items is dependent on the similarity between that list and previously seen lists (Watkins & Watkins, 1975). Kane and Engle (2000), for instance, had participants read four lists of words. Importantly, the first three lists consisted of words expressing concepts belonging to the same semantic category (e.g., animals), whereas the fourth list consisted of words denoting concepts belonging to a different category (e.g., countries). Results showed that performance, measured as number of words retrieved, decreased from list 1 to list 3 and increased from list 3 to list 4. This pattern of results, consistently found across studies, shows that items seen at list 1, which are no longer relevant, may still interfere with retrieval of items seen at list 2 or 3, a phenomenon that was termed *proactive interference*. A popular interpretation of this effect is that people use the semantic category as a retrieval cue (Watkins & Watkins, 1975, Nairne, 2002). It follows that by list 2 or 3, the cue becomes overloaded – i.e., associated with many items – and performance decays. At list 4, on the other hand, the category cue used for retrieval uniquely specifies the items from that trial, and performance improves – a phenomenon termed *release from interference.*

Cue-based parsing models propose that similar factors contribute to interference in sentence processing, namely interference from cue-based retrieval processes. To understand why, let us review the main assumptions of this framework.

Cue-based parsing models argue that sentence constituents are not actively maintained in memory, as proposed by capacity models; rather, they are passively stored. Support for this comes from experiments with the speed-accuracy tradeoff paradigm (SAT) (McElree, Foraker & Dyer, 2003; McElree, 2006), showing that, whereas adjacent dependencies are processed faster than non-adjacent dependencies, the processing speed of non-adjacent dependencies is not modulated by the number of intervening constituents (McElree, Foraker & Dyer 2003, for relative clauses and subject-verb dependencies; Martin & McElree, 2008, 2009, for ellipsis; Martin & McElree, 2011, for sluicing; Foraker & McElree, 2011, for a review). This runs contrary to what one would expect if constituents were maintained in memory, since the probability of successful maintenance should decrease with distance. Moreover, research with cross modal lexical decision tasks (Nicol & Swinney, 1989) has shown that semantic associates of the antecedent in filler-gap dependencies are recognized faster (i.e., primed) than control words at the gap region, but not in a previous region between the filler and the gap (but see Wagers and Phillips, 2014 and Ness and Meltzer-Asscher, 2017 for evidence that some features of the filler may be maintained).

If we accept that constituents are not generally maintained, we may postulate that they are retrieved. In cue-based parsing, retrieval is achieved by retrieval cues derived from the linguistic context and grammatical knowledge. These cues are assembled and form a probe that is matched in parallel against all constituents stored in memory, and the constituent that best matches the probe is the most likely to be retrieved[14]. The retrieval process that we are describing is an example of content-addressability, wherein items are accessed based on their content. Importantly, since distractors, i.e., constituents similar to the correct target of a dependency, are also targeted by the probe, they may interfere in the retrieval process: as in the Brown-Peterson example, a cue may become overloaded, i.e., associated with many items, reducing its distinctiveness and the likelihood of successful retrieval of the target. In other words, retrieval success increases as a function of the match between the probe and the target, but decreases as a function of the match between the probe and the distractors in memory.

To see how this mechanism could work, let's consider the approach by Van Dyke (2007) for the following *long-distance subject-verb dependency* (16)[15], based on the computational model of Lewis & Vasishth (2005), which embodies the general assumptions of cue-based parsing (see Figure 2 for a schematic representation of syntactic interference effects, which are discussed below).

(16) The pilot remembered that the lady who said that the seat was smelly moaned.

(Van Dyke, 2007: 426)

[14] Data from experiments with the SAT paradigm (Foraker & McElree, 2011) are consistent with a parallel direct access retrieval mechanism, since, as mentioned above, processing speed does not depend on dependency distance, contrary to what would be expected if memory access proceeded via a search mechanism (McElree, 2006).

[15] Again, it should be noted that *long-distance subject-verb dependency* refers to a context in which the head noun of the subject is non-adjacent to the verb that assigns a thematic interpretation to the subject. Van Dyke (2007) and other proponents of cue-based parsing often refer to nouns such as *lady* (in 16) as the subject NP. However, the syntactic subject of (16) is the whole constituent *The lady who said that the seat was smelly*, so that in cases such as this, it is not adequate to say that the subject is nonadjacent to the verb, as noted by Santi, Grillo, Molimpakis & Wagner, 2019. Nevertheless, in the model presented by Van Dyke (2007) and in related cue-based parsing accounts, it is assumed that resolution of subject-verb dependencies involves retrieval of information associated with the subject head noun, assumed to head the whole subject, which provides an explanation for interference effects between the head noun of the subject and other nouns that are part of the subject, as is discussed below.

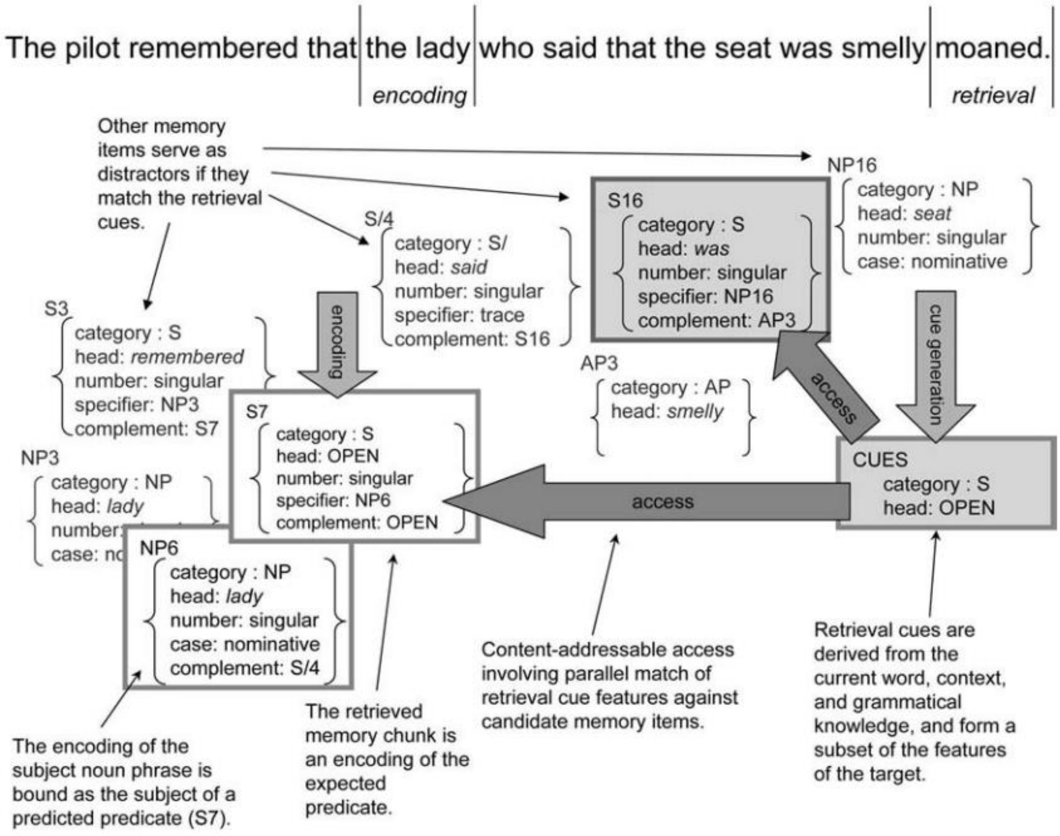

Figure 2. Representation of cue-based parsing (taken from Van Dyke, 2007: 426).

The critical dependency is that between the subject head noun *lady* and the verb *moaned*. In cue-based parsing, the noun *lady* is assumed to be encoded in memory as a feature bundle, including not just syntactic features associated with the item itself, e.g., [Category: NP; Number: Singular; etc.], but also features related to the broader syntactic context, e.g., the NP headed by *lady* is encoded as (part of) the subject of a clause that is missing a predicate[16], which may be represented by [Category: S; Head: Open], where *S* represents a clause. This feature bundle is passively stored, as noted. So, when the verb *moaned* is seen, a probe is assembled for retrieval of a clause that is missing a predicate. Now, this probe is composed of cues that consist of a subset of the features associated with the target, such as [Category: S; Head: Open], and it is matched against all previously encoded constituents in memory. Interference is

[16] In what consists of a syntactic prediction. Here, it is assumed that the subject of the verb is an NP, but the cue-based parsing account is consistent with the DP hypothesis (Lewis, Vasishth & Van Dyke, 2006).

therefore expected to accrue when cues of the probe match distractors. For instance, since *the seat* was encoded as subject of a clause [Category: S], its features partially match the retrieval probe and interfere in the retrieval process (though it misses features that specify the correct target, such as [Head: Open]). Similar effects are expected to occur due to the presence of *the pilot* in memory. This is a possible implementation of the syntactic interference effects found in Van Dyke (2007), reviewed above. Although the computational model of Lewis and Vasishth (2005) includes only syntactic features, this reasoning could be extended to semantic features. For instance, the retrieval probe triggered by the verb may be expected to include a cue that specifies that the clause into which the verb is to be integrated must have a subject headed by an animate noun (since only animate entities moan). If so, then *the pilot* is expected to interfere with retrieval of *the lady* in (16), since both are encoded with a [+animate] feature.

It should be noted that it is not entirely clear how the mechanism described above would explain the results obtained in Gordon, Hendrick and Johnson (2001), reviewed in section 1.4.1, where common nouns were shown to interfere with each other, but not with proper names. The reason for this is that noun type cannot be a retrieval cue used by the verb. Van Dyke and McElree (2006) propose that the results of Gordon, Hendrick and Johnson (2001) may still be attributed to retrieval processes if one assumes that proper names and pronouns are less semantically rich than common nouns, resulting in differential matches with the same retrieval probe. Although possible in principle, this explanation remains speculative.

1.4.3. Individual differences in resolving interference

Some proponents of cue-based parsing have suggested that individual differences in resolution of interference in sentence processing may depend not as much on working memory capacity as on inhibitory processes involved in resisting memory interference and on the quality of a subject's lexical representations, assuming that richer representations may be more distinctive and less susceptible to interference (Van Dyke, Johns & Kukona, 2014).

Van Dyke, Johns and Kukona (2014) investigated individual differences in resolving sentence semantic interference caused by an external memory load. They found that performance in the listening span task, i.e., a version of Daneman and Carpenter's (1980) task in which participants hear sentences instead of reading, modulated the size of the interference effect in comprehension accuracy, with interference effects reducing as a function of working memory capacity. However, this effect disappeared when variance shared with IQ was partialled out from the listening span. Van Dyke, Johns and Kukona (2014) suggested that previous results implicating working memory in sentence processing may be due to variance shared with other constructs, highlighting the importance of including different measures in studies of individual differences. On the other hand, it was found that higher scores in the Peabody picture task, used as an index of lexical knowledge, predicted smaller interference effects in comprehension even after controlling for shared variance with IQ. This result suggests that subjects with more lexical knowledge and, presumably, richer lexical representations are less susceptible to interference, consistently with the cue-based parsing approach.

In contrast, Tan, Martin and Van Dyke (2017) showed that better performance on the vocabulary subtest of the WAIS-III (indexing more lexical knowledge) predicted larger syntactic and semantic interference effects in sentence comprehension accuracy. Clearly, more research is needed. Importantly, Tan and colleagues (2017) found that a measure of inhibitory functions, the Stroop task, which requires that participants name the colors in which names of colors are written, while resisting/inhibiting the "urge" to read the names instead, did not correlate with the size of interference effects in online or offline measures of sentence comprehension. This result runs contrary to the predictions of the cue-based parsing approach.

However, as noted by Tan and colleagues, it may be that the Stroop task does not reflect the right kind of inhibition: whereas in the Stroop task participants are required to inhibit a prepotent response to a stimulus, in sentence processing, participants may be required to inhibit memory competitors that are responsible for the interference. This notion is consistent with factorial analyses showing that the Stroop task loads in a different factor from that in which tasks measuring resistance to proactive interference load, e.g., Brown-Peterson task (Friedman & Miyake, 2004; Pettigrew & Hillis, 2014).

In sum, it is still not clear whether either verbal knowledge or resistance to interference modulate interference effects in sentence processing. It is important to stress, however, that, analogously to capacity models, one does not need to endorse a non-modular view of language to accept a cue-based parsing explanation of syntactic processing (Lewis & Vasishth, 2005). Syntactic processing may operate according to principles of cue-based parsing models in a functionally isolated manner, thus not sharing resources with other tasks and processes.

1.5. Minimality approach to sentence processing complexity

The memory models reviewed so far attribute complexity effects in sentence processing to general principals of Psychology, such as memory decay and interference, thus providing a bridge between the study of language processing and general Cognitive Psychology. In these accounts, intervention effects depend on how syntactic knowledge is implemented in memory during performance; the nature of the grammar (i.e., competence) is less important. The minimality approach, which we will now review, significantly departs from these accounts. It proposes instead that some complexity effects in sentence processing, namely those that result from configurations in which there is (hierarchical) intervention, result from a grammatical principle that constrains syntactic movement (i.e., Relativized Minimality), thus providing a bridge between the study of language processing and theoretical Linguistics. In this framework, competence takes precedence over implementation in performance. Effects of intervention are therefore predicted to depend on the grammatical nature of particular structures.

1.5.1. Generalized Minimality in agrammatism

The minimality account proposes that the processing asymmetry between SR and OR (as well as other asymmetries between structures involving subject and object wh-movement) results from grammatical constraints. Intuitively, it is proposed that structures in which there is movement of a constituent across a similar constituent are hard to process. These models can be traced back to Grillo's work on agrammatism (Grillo, 2005, 2009), which we shall briefly present.

Agrammatic Broca's aphasics are individuals with frontal lobe lesion who, in addition to language production deficits (so called "telegraphic speech", characterized by frequent omission of functional linguistic material), are known to display comprehension deficits on semantically reversible sentences with non-canonical order of thematic role assignment (Grillo, 2009, Grodzinsky, 2000), e.g., object relative clauses and passives, but not on sentences with canonical order of thematic-role assignment, e.g., subject relative clauses and active sentences. These selective comprehension deficits are called *canonicity effects*. In Grillo (2009), it is proposed that canonicity effects may be derived from general principles of syntax, i.e., locality constraints on movement, or minimality, assuming that the representation of scope-discourse-related morphosyntactic features is impaired in agrammatic individuals. The right notion of locality here is that of Relativized Minimality, which we must introduce before proceeding.

Relativized Minimality (RM) is a general approach to locality constraints in syntactic dependencies, cutting across different kinds of structures. It is mostly discussed in contexts of movement, but it may apply to other dependencies. It expresses the notion that some syntactic dependencies must be satisfied in the minimal structural configuration in which they can be satisfied. Formally, and according to Rizzi (2013):

In the configuration … X … Z … Y …

e.g., * **How** do you wonder ***which problem*** to solve <which problem> **<how>** ?
X **Z** **Y**

(Rizzi, 2013: 177)

X and Y cannot be connected by movement (or other local relations) if (i) Z intervenes between them, (ii) and Z is of the same structural type as X.

In this model, intervention is defined hierarchically, not linearly. A constituent Z is said to intervene between X and Y if X c-commands Z and Z c-commands Y. C-command, in turn, refers to a structural configuration: a syntactic node A c-commands a syntactic node B if, and only if: i) either B is A’s sister; ii) or A’s sister contains B (Adger, 2003). For instance, in the tree represented by Figure 3, Z c-commands both S, its sister node, and W and R, which are contained in S. Z does not, however, c-command X, Y and T, since they are not sisters of Z nor contained in sisters of Z.

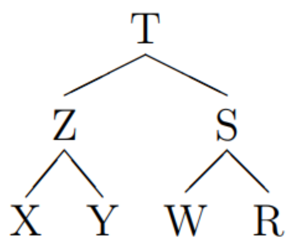

Figure 3. Representation of a syntactic tree (taken from Adger, 2003: 93).

"Same structural type", on the other hand, may be defined in different ways. Here, we will adopt Rizzi's (2013) latest approach in terms of featural constitution, such that Z is of the same structural type as X if Z fully matches the specification of X in the relevant morphosyntactic features, i.e., the features involved in the target dependency.

RM is a powerful concept that predicts a wide range of contrasts in grammaticality. For instance, RM correctly predicts selective blocks on movement relations in indirect questions, so called wh- islands (*island* is a metaphorical term used to refer to certain contexts from which a constituent cannot be moved). Consider the asymmetry in (17).

(17) a. ? Which problem do you wonder *how* to solve <which problem> <how> ?

b. * How do you wonder *which problem* to solve <which problem> <how> ?

(Rizzi, 2013: 178)

While the structure in (17a) is acceptable, the structure in (17b) is not. The first step in explaining this difference consists in noting that the relevant featural specifications of *which problem* and *how* differ. While both elements are question operators, therefore assumed to contain the feature [+Q], involved in triggering movement, *which problem* also contains a lexical specification, introduced by the noun *problem*. Importantly, this lexical specification, which restricts the range of the variable introduced by the question, is assumed to be relevant in triggering movement of *which problem* (see Rizzi, 2013, especially footnote 9, and references therein for arguments). Therefore, the relevant set of features for movement in *which problem* is [+Q, +NP], while the relevant set of features for movement in *how* is [+Q]. Getting back to the contrast in (17), movement is thus blocked by RM in (17b) because *which problem* intervenes between *how* and the empty position assumed to be filled by a copy of *how* (<how>) and the relevant featural specification of *which problem* [+Q, +NP] fully matches that of *how*

[+Q]. On the other hand, movement is permissible in (17a), since the relevant featural specification of the intervening element *how* [+Q] does not fully match the relevant featural specification of the moved element *which problem* [+Q, +NP].

So, how can RM help explain canonicity effects? Let's consider the relative clauses in (1, repeated in 18 for convenience).

(18) a. The musician$_i$ that criticized __$_i$ the painter

b. The musician$_i$ that the painter criticized __$_i$

As noted, comprehension of OR (18b) is impaired in agrammatic individuals. In this structure, the embedded subject *the painter* hierarchically intervenes between the moved element *musician* and the empty position ("__"), therefore satisfying the first condition for RM block. However, the relevant featural specification of *musician*, assumed to be [+R, +NP] (following Friedmann, Belleti & Rizzi, 2009), where [+R] is a feature assumed to be involved in triggering movement of the relativized nominal expression and [+NP] is a lexical restriction, is not fully matched by the relevant featural specification of *the painter* [+NP]; thus, the second condition for RM block is left unsatisfied and movement is allowed. However, as Grillo (2005, 2009) realized, if the feature(s) that distinguish *the musician* from *the painter* (which we are assuming is [+R], following Friedmann, Belleti & Rizzi, 2009) is/are not mentally represented, then both elements will be represented as structurally identical (with the featural specification [+NP]). In this case, RM will block the dependency.

In Grillo (2005, 2009), it is proposed that representation of scope-discourse-related features (i.e., features related to questions, relativizations and focus, such as [+Q] or [+R], in Rizzi's formulation), which are assumed to be involved in triggering movement in sentences with non-canonical order of thematic role assignment, and which structurally distinguish moved elements from intervening elements, is impaired in agrammatic Broca's aphasics, possibly due to slow syntactic processes (Zurif, Swinney, Prather, Solomon & Bushell, 1993). As a result, grammatical constructions in which there is (hierarchical) intervention, such as OR, will be ruled out as ungrammatical, since the moved element will not be distinguished from the intervening element(s), and comprehension will decay. Structures in which there is movement but no intervention, such as SR, on the other hand, will not be ruled out, and comprehension will be intact. Canonicity effects are thus treated as an interaction between a preserved RM system and a deficient system for representation of scope-discourse-related features.

1.5.2. Generalized Minimality in child and adult grammar

Friedmann, Belleti and Rizzi (2009) extended Grillo's minimality approach to syntactic complexity to acquisition. As was previously noted, acquisition of OR stabilizes later in development than acquisition of SR. Typically, until at least the age of six, children reveal comprehension deficits with OR, but not with SR. However, not all OR are equal in the minds of children. Comprehension of OR is modulated by structural similarity between the relative head (i.e., moved element) and the embedded subject. Friedmann, Belleti and Rizzi (2009) found the typical asymmetry between SR (19a for example of the stimuli) and OR (19b for example of the stimuli) with stimuli containing lexically-restricted NPs. Comprehension of OR by Hebrew children with mean age of 4.6 years old was at or near chance level, as assessed by sentence-picture and sentence-scenario matching tasks, while comprehension of SR was good (with near 90% correct answers).

(19) a. Tare li et ha-para she-menasheket et ha-tarnegolet.

show to-me ACC the-cow that-kisses ACC the-chicken

'Show me the cow that is kissing the chicken.'

b. Tare li et ha-pil she-ha-arie martiv.

show to-me ACC the-elephant that-the-lion wets

'Show me the elephant that the lion is wetting.

(Friedmann, Belleti & Rizzi, 2009: 70)

However, when free relatives were used (SR – 20a, OR – 20b), wherein the moved element is a pure WH-operator (i.e., roughly corresponding to *who*), containing no lexical restriction, comprehension by the same children was found to be equally good for SR and OR.

(20) a. Tare li et mi she-martiv et ha-yeled.

show to-me ACC who that-wets ACC the-boy

'Show me the one that is wetting the boy.

b. Tare li et mi she-ha-yeled menadned.

show to-me ACC who that-the-boy swings

'Show me the one that the boy is wetting.'

(Friedmann, Belleti & Rizzi, 2009: 73, 74)

Similarly, good comprehension of OR was found when the moved element contained a lexical restriction, but the embedded subject did not (the subject was an impersonal arbitrary null pronominal element, *pro*) (21).

(21) Tare li et ha-sus she-mesarkim oto.

show to-me ACC the-horse that-brush-pl him

'Show me the horse that someone is brushing.'

(Friedmann, Belleti & Rizzi, 2009: 75)

In sum, only when both the moved element and the embedded subject of the OR contain lexical restrictions are there comprehension deficits in children. Friedmann, Belleti and Rizzi (2009) proposed that the child grammar adheres to a stricter version of RM, such that not just dependencies in which the featural configuration of the target is identical to that of the intervener are blocked, but also structures in which the featural configuration of the target is partially matched by that of the intervener. In other words, adults allow configurations in which the featural specification of the intervener is properly included in the featural specification of the target, but children do not. (19b) is thus blocked in children's grammar, since the featural specification of the intervener ([+NP]) is properly included in that of the target ([+R, +NP]). Conversely, (20b) and (21) are allowed, since the intervener and the target do not share relevant features. This proposal has been very influential in the acquisition literature and there are plenty of studies showing that features other than the one related to the lexical restriction modulate intervention effects (e.g., Adani, Lely, Forgiarini & Guasti, 2010, for gender and number, Bentea, Durrleman & Rizzi, 2016, for animacy).

Most importantly for our purposes, Grillo's Generalized Minimality approach has also been extended to adult processing. Friedmann, Belleti and Rizzi (2009) speculated that the stricter grammar of the child may be a consequence of processing limitations, more specifically, memory constraints, a notion that was adopted in Bentea, Durrleman and Rizzi (2016). From this perspective, the lower memory capabilities of children prevent them from calculating the inclusion relation that holds between the featural specification of the target and that of the intervener in structures such as OR, which is assumed to be computationally demanding. Importantly, the well-established asymmetry between SR and OR could be reinterpreted in a new light in the case of adult processing: while adults generally accept structures such as OR, the computational load associated with featural intervention may still render these structures hard to process (Belleti & Rizzi, 2013). The results obtained by Gordon, Hendrick and Johnson (2001), showing that changing the intervener noun type from a description to a proper name facilitates processing of OR, follow, if the featural specification of proper names is not included in the featural specification of the target (i.e., moved NP) – see discussion in Belletti & Rizzi (2013: 306).

Costa, Grillo and Lobo (2013) have proposed a different account of minimality effects in OR and other similar structures. In their view, complexity effects result from failure to activate the features that allow the target to be distinguished from the intervener (i.e., scope-discourse-related features). Whenever a crucial distinguishing feature is not properly activated, minimality ensues. The authors conducted a self-paced reading study that tested processing of European Portuguese indirect questions involving movement from subject position (22a and 23a) and movement from object position (22b and 23b). Participants read sentences containing dependencies wherein the moved element was either not lexically restricted (22) or lexically restricted (23).

(22) a. A advogada contou ao juiz [quem estava a corromper o político **com dinheiro público**].

‘The lawyer told the judge who was corrupting the politician with public money.’

b. A advogada contou ao juiz [quem o político estava a corromper **com dinheiro público**].

‘The lawyer told the judge whom the politician was corrupting with public money.’

(23) a. A advogada contou ao juiz [que político estava a corromper o presidente **com dinheiro público**].

‘The lawyer told the judge which politician was corrupting the president with public money.’

b. A advogada contou ao juiz [que político o presidente estava a corromper **com dinheiro público**].

‘The lawyer told the judge which politician the president was corrupting with public money.’

(Costa, Grillo & Lobo, 2013: 153)

The data from comprehension questions revealed that the complexity effect of object movement was larger when the moved element was lexically restricted, whereas the data from reading times did not reveal a difference between complexity effects of object movement in dependencies with or without lexical restriction: there was an effect of extraction site, with subject dependencies being read faster than object dependencies at the embedded clause excluding the PP (in bold), and an effect of the presence of lexical restriction, with faster reading times when no lexical restriction is present, but no interaction between the two variables. Costa, Grillo and Lobo (2013) proposed that while the moved wh-pronoun *quem* (in 22) is not lexically restricted, it still possesses a rich internal structure, comprising features such as [+animate, +human, +singular], which are shared with the intervener and which may activate RM if scope-discourse related features are not properly activated. In this model, the more features that are necessary to distinguish target from intervener, the more likely it is that features are not properly accessed and activated and that a RM block ensues. Furthermore, costly and time-consuming lexical access processes, such as those required to access a lexical restriction, may likewise be expected to reduce the odds of properly activating distinguishing features, therefore explaining why headed OR induce stronger complexity effects (Costa, Grillo & Lobo, 2013).

1.5.3. Speculating on individual differences in minimality effects

Adopting Friedmann, Belleti & Rizzi's (2009) account of minimality effects, one may speculate that general working memory capacity may modulate complexity effects of OR (and other structures involving movement over an intervener), assuming that the system for syntactic processing is not modular. In fact, such an approach was taken in recent work by Bentea, Durrleman and Rizzi (2016), who proposed that greater general memory capacity in children facilitates calculation of the inclusion relation in OR. Adopting a similar stance for adults follows naturally, since the model proposes continuity in intervention effects across development.

In contrast, adopting Costa, Grillo and Lobo's (2013) account of Minimality effects in adult processing, one could consider that individual differences in lexical access ability may modulate OR complexity, since less costly and more efficient lexical access may be expected to increase the likelihood of activating different features, including those that distinguish the target from the intervener. Thus, both working memory capacity and lexical access abilities emerge as possible predictors of processing syntactic complexity in structures involving movement.

1.5.4. Relativized Minimality and control

SC (24) instantiates a syntactic dependency between a DP in the superordinate clause (i.e., *the musician*) and the position of the subject of the embedded verb (i.e., *write*) across an intervener, which is an argument in the superordinate clause (i.e., *the painter*).

(24) the musician$_i$ promised the painter __$_i$ to write a book.

If control is movement, as has been recently proposed (Hornstein, 1999), Relativized Minimality necessarily applies and SC is grammatically on a par with OR: a movement dependency is established across an intervener. The delay in acquisition of SC could therefore be attributed to featural intervention, as has been proposed for the delay with OR (Friedmann, Belleti & Rizzi, 2009), and complexity effects in adult processing of SC parallel to those found for OR could be expected for the same reason. If, on the other hand, control is not movement, complexity effects in acquisition or adult processing of SC parallel to those of OR are not anticipated on the basis of featural intervention.

Belleti and Rizzi (2012) propose an alternative account of the delay in acquisition of SC, also based on Relativized Minimality. According to this account, difficulty in acquisition of SC is not due to featural intervention, as is assumed to be the case with OR (Friedmann, Belleti & Rizzi, 2009), but to problems with a syntactic operation assumed to allow intervention to be avoided in SC – smuggling (see Belleti & Rizzi, 2012 for details). If smuggling justifies higher processing cost in adulthood, the prediction of an adult processing asymmetry between SC and OC could be justified by this account. However, this asymmetry would not be expected to parallel that between SR and OR, since the nature of potential problems with SC is assumed to differ from the nature of the problem with OR.

1.6. Goals of the present study

The first goal of this study is to assess whether relative clauses and control structures reveal parallel processing asymmetries, with similar complexity effects in the structures that involve intervention in the filler-gap dependency: SC and OR. The second goal is to investigate whether and how general resistance to interference, verbal knowledge, general working memory capacity and lexical access ability modulate processing of relative clauses and control structures.

1.7. Predictions of the DLT, cue-based parsing and minimality approach for processing of relative clauses and control structures in European Portuguese.

We will now consider, in turn, predictions of the Dependency Locality Theory, the cue-based parsing account and the minimality approach for processing of relative clauses and control structures in European Portuguese (see (25) a SR, (26) an OR, (27) a case of SC, (28) a case of OC). We will be concerned only with structures in which both the antecedent of the filler-gap dependency and the intervening NP are descriptions (i.e., lexically restricted).

(25) O músico$_i$ que __$_i$ criticou o pintor escreveu um livro
the musician$_i$ that __$_i$ criticized the painter wrote a book

(26) O músico$_i$ que o pintor criticou __$_i$ escreveu um livro
the musician$_i$ that the painter criticized __$_i$ wrote a book

(27) O músico$_i$ prometeu ao pintor __$_i$ escrever um livro
the musician$_i$ promised PREP-the painter __$_i$ write a book

(28) O músico convenceu o pintor$_i$ a __$_i$ escrever um livro
the musician convinced the painter$_i$ PREP __$_i$ write a book

We will consider both predictions of syntactic complexity and predictions of individual differences, if assuming a non-modular view of the system responsible for syntactic processing[17].

The DLT (Gibson, 2000), taken as representative of capacity models, predicts greater complexity in OR than in SR, as already discussed. In short, resolution of the filler-gap dependency at the empty position site, which is the point of differential processing between SR and OR, is expected to be more costly in OR, since it crosses two expressions introducing new discourse referents in OR and none in SR. As for control, the DLT predicts greater complexity in SC than in OC. The only point of differential processing between the two constructions[18] is the empty position site, which requires resolution of the filler-gap dependency: whereas in SC it crosses two expressions introducing new discourse referents, i.e., *prometeu*, and *o pintor*, in OC it crosses none. In sum, under DLT, parallel processing asymmetries are expected for relative clauses and control structures, with greater difficulty in the cases of OR and SC, in which there is memory overload due to intervention. As for individual differences, the DLT predicts a differential effect of working memory capacity on processing of relative clauses and processing of control structures, with stronger modulatory effects in both OR and SC, since memory demands are higher.

The cue-based parsing account (Lewis, Vasishth & Van Dyke, 2006) predicts greater complexity in OR than in SR. Difficulty with OR processing is expected to occur when the moved element is retrieved at the empty position site, since there is a similar noun in memory (the head noun of the embedded subject) that causes interference. In SR, on the other hand, there is no distractor in memory to interfere with the gap-filling process. An additional source

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[17] As previously noted, if the system for syntactic processing is a cognitive module (Caplan & Waters, 1999), no resources are shared between syntactic processing and other tasks, and effects of syntactic complexity are not expected to depend on general processes of memory, vocabulary or lexical access ability. We return to this important point in the discussion.

[18] As before, we consider only integration costs. Storage costs should be roughly the same in SC and OC.

of difficulty in OR could be expected when resolving the subject-verb dependency at the embedded verb site, assuming that the head of the matrix subject interferes with retrieval of the head of the embedded subject[19] (Tan, Martin & Van Dyke, 2017). As for control, the cue-based parsing account predicts greater complexity in SC than in OC. Assuming that both SC and OC require retrieval of the filler at the empty position site, we predict that both in SC and in OC there will be interference caused by a similar constituent in memory, i.e., the matrix object and the matrix subject, respectively. Crucially, in the case of SC the interference is retroactive (the distractor is more recent than the target), whereas in the case of OC the interference is proactive (the distractor is older than the target), and retroactive interference has been shown to be more detrimental to sentence processing than proactive interference (Martin & McElree, 2009; Van Dyke & McElree, 2011), in line with predictions from the computational model of Lewis & Vasishth (2005). In sum, under the cue-based parsing account, parallel asymmetries between relatives and control are also expected, with greater difficulty for SC and OR, cases in which there is memory interference due to intervention. As for individual differences, it is expected that capacity to resist interference in memory and lexical knowledge (which, presumably, is associated with more robust lexical representations, expected to be less susceptible to interference) differentially affect processing of relative clauses and processing of control structures, with stronger modulatory effects in OR and SC, where interference is expected to be higher.

The minimality approach predicts that OR are harder to process than SR, as has been discussed. In short, complexity in OR may result either from computational demands of calculating a featural inclusion relation between intervener and target (Friedmann, Belleti & Rizzi, 2009) or from RM block due to failure to activate the features associated to the target

[19] There is, however, evidence that suggests that adjacent subject-verb dependencies do not require retrieval (McElree, Foraker & Dyer, 2003), casting doubt on the validity of this assumption.

and the intervener (Costa, Grillo & Lobo, 2013). Since in SR there is no intervention, no complexity is expected. Predictions for control, on the other hand, crucially depend on the syntactic processes assumed to be involved in its derivation. If control is analyzed as movement, then SC may be expected to be more complex than OC, for the same reasons that apply to relative clauses – i.e. movement crosses an intervener in SC, but not in OC[20], and parallel asymmetries between relative clauses and control may be expected. However, if control is not movement, no parallel asymmetries between SC and OC are anticipated. One may still, however, expect an asymmetry between SC and OC if a *smuggling* analysis of SC is adopted (Belleti & Rizzi, 2012), though not parallel to the asymmetry between SR and OR. As for individual differences, Friedmann, Belleti and Rizzi's (2009) featural inclusion account of complexity predicts that working memory capacity has differential effects on relative clauses, with a stronger modulatory effect on OR, where a featural inclusion relation is calculated. Differential effects of working memory on control structures are also expected if control is movement, with greater effects on SC. Costa, Grillo and Lobo's (2013) account, on the other hand, should predict that the ability to access the lexicon differentially affects relative clauses, with a stronger effect on OR, where the efficiency of access to the lexical representation of the moved element may increase the likelihood of activation of scope-discourse-related features that distinguish the moved element from the intervener. Under the same hypothesis, differential effects of lexical access ability on control structures are also expected if control is movement, with stronger modulatory effects on SC.

[20] Assuming that the "a" introducing the indirect object in SC (see 27) is not a preposition, but a dative case marker (see Gonçalves, 2015 for arguments).

2. Methods

2.1. Participants

Seventy-four (68 females) healthy participants took part in the study. All were right-handed, native speakers of European Portuguese, with no language or reading disability, and had normal or corrected to normal vision. Participants' ages ranged from 17 to 41 years old (*M* = 19.7, *SD* = 4.4). All participants gave informed consent to the experimental procedure, which was approved by the Ethics Committee of the Faculty of Psychology of the University of Lisbon.

Five participants were excluded from the analysis due to atypical performance in the sentence comprehension task: two participants had low accuracy in answering sentence comprehension probes (lower than 67%), one participant had exceptionally long response times (with mean reading time greater than 3 standard deviations of the sample mean), one participant had exceptionally long reading times (with mean response time greater than 3 standard deviations of sample mean) and one participant reported failing to read naturally (by consciously trying to memorize every sentence). The remaining sixty-nine participants constituted the final sample.

2.2. Materials and Procedure

The tasks were administered individually in a single session, lasting approximately 1.5h. Testing was conducted in a quiet room and computerized tasks were always run in the same computer. Participants were told that they could take intervals between the tasks whenever necessary. The order of the tasks was kept constant for all participants, to avoid confounding individual differences with task order effects: Sentence comprehension task, Brown-Peterson task, vocabulary subtest (WAIS-III), Reading Span, semantic fluency task.

2.2.1. Sentence comprehension task

To assess whether processing of relative clauses is comparable to that of control, we developed a sentence comprehension task, involving self-paced reading, in which participants read sentences and answered comprehension questions about the sentences they read. Complexity effects of syntactic processing were evaluated using three different measures: accuracy, i.e., proportion of correct responses to probe comprehension questions, response times, i.e., latency of response to probe comprehension questions, and reading times, i.e., time spent reading each word/region of the sentence.

Materials

We constructed 30 pairs of sentences with relative clauses, one a subject relative clause (SR condition, see (29a)) and the other an object relative clause (OR condition, see (29b)). Another 30 pairs of sentences with control dependencies were also created, one a subject control dependency (SC condition, see (30a) and the other an object control dependency (OC condition, see (30b)). For a complete list of the experimental sentences, see Appendix I.

(29) a. O músico que criticou o pintor escreveu um livro

the musician that criticized the painter wrote a book

'*The musician that criticized the painter wrote a book*'

b. O músico que o pintor criticou escreveu um livro

the musician that the painter criticized wrote a book

'*The musician that the painter criticized wrote a book*'

(30) a. O músico prometeu ao pintor escrever um livro

the musician promised PREP -the painter write a book

‘*The musician promised the painter to write a book*’

b. O músico obrigou o pintor a escrever um livro

the musician forced the painter PREP write a book

‘*The musician forced the painter to write a book*’

Sentences with relative clauses within each pair differed only in the order of the words inside the relative clause: the embedded verb could either precede the NP, yielding a sentence with a SR, or follow the NP, yielding a sentence with an OR. All sentences in SR and OR conditions were 9 words long and had the same structure as those in (29).

Sentences with control dependencies within each pair differed in the type of control verb (i.e., main verb). Whereas sentences in the SC condition were constructed with subject control ditransitive verbs, sentences in the OC condition were constructed with object control verbs. Since there is a very limited number of ditransitive verbs that are subject control verbs in European Portuguese, only five control verbs could be used for constructing the thirty SC sentences (*jurar* ‘swear’, *prometer* ‘promise’, *assegurar* ‘assure’, *ameaçar* ‘threaten’, *garantir* ‘guarantee’) and another five control verbs were used for constructing the thirty OC sentences (*obrigar* ‘obligate’, *forçar* ‘force’, *convencer* ‘convince’, *autorizar* ‘authorize’, *encorajar* ‘encourage’). SC sentences with *ameaçar,* such as (31), as well as OC sentences (see 30b) were 9 words long, whereas the remaining sentences with control dependencies were 8 words long. This difference was due to the occurrence of an extra preposition before the embedded verb in OC sentences and in SC sentences with *ameaçar*.

(31) A violinista ameaçou a médica de abandonar o grupo

the violinist threatened the doctor PREP abandon the group

‘*The violin player threatened the doctor of leaving the group*’

Apart from the difference in control verbs, pairs of SC and OC sentences were identical (considering the noun phrases used, as well as the embedded verb), and had the same structure as those in (30).

Wherever possible, we used the same lexical material for constructing sentences in relative clause conditions and sentences in control conditions, as illustrated in (29) and (30). Sentences were thus constructed in sets, such that each set contained a pair of sentences with relative clauses and a pair of sentences with control dependencies. Sentences from the same set contained the same NPs. The embedded verbs differed, since forcing sentences with relative clauses and sentences with control dependencies to have the same embedded verbs would compromise plausibility. Importantly, embedded verbs in sentences with relative clauses and sentences with control dependencies were matched in number of syllables, $t(58) = -1.027$, $p = .309$, and number of characters, $t(58) = -.623$, $p = .535$. The main verbs also differed. The main verbs of sentences with relative clauses were the verbs used in the complement clauses of control sentences, to maximize content identity across sentences with relative clauses and control sentences, whereas the main verbs of control sentences were necessarily control verbs.

NP1 (i.e., *músico*) and NP2 (i.e., *pintor*) were always descriptions of professions matched in gender and number, to ensure interference was maximal in all sentences. Furthermore, NP1 and NP2 were selected so that there were no inherent authority relationships between them, which could bias interpretation of control structures (e.g., with verbs such as *force*: for instance, it is plausible that a judge would force a lawyer to do something, but not that a lawyer would force a judge to do something). The verbs (except for control verbs) were always common transitive verbs describing actions. NP3 (i.e., *livro*) was always a description of an inanimate entity. All experimental sentences were constructed so that there were no inherent semantic relationships between the NPs and the verbs (e.g., if the profession *writer* were included in a sentence, propositions related to writing would be avoided).

To reduce potential exposure effects, participants saw only two sentences from each set, one with a relative clause and one with a control dependency. In total, participants saw 15 sentences from each condition (SR, OR, SC and OC). In sentences with control dependencies, participants saw each control verb three times.

Sixty additional sentences were included as fillers (structures involving coordination, finite complement clauses and temporal clauses). Fillers were syntactically different from the experimental sentences but had equal number of clauses and similar length. Filler sentences were included to divert participants' attention from the manipulations of interest and reduce the likelihood of adoption of conscious strategies in parsing

Procedure

Sentences were presented in a word-by-word self-paced manner, with a moving window display (see Figure 4).

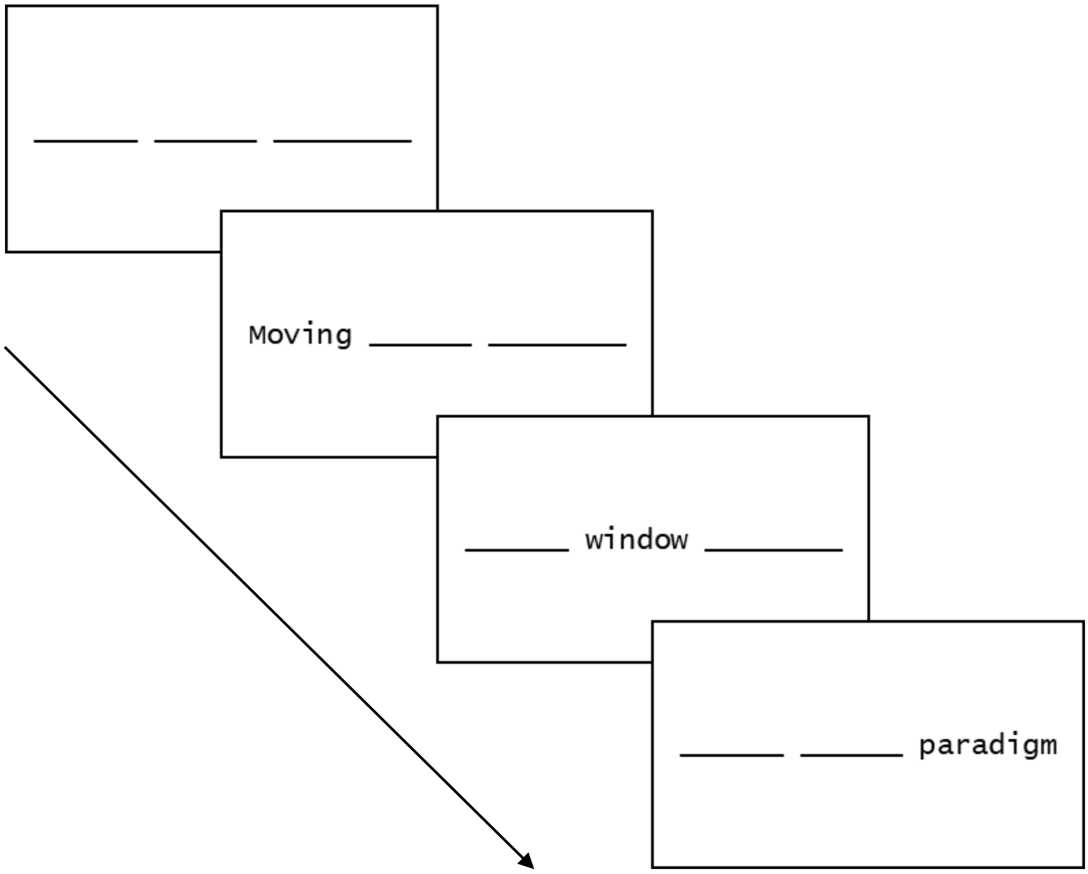

Figure 4. Representation of the self-paced reading time progression for the expression *Moving window paradigm.*

We chose self-paced presentation with moving window because it yields patterns of reading times similar to those found in more naturalistic reading settings, such as unrestricted reading tasks in eye-tracking studies (Just, Carpenter & Woolley, 1982). Furthermore, word-by-word presentation was preferred to phrase-by-phrase presentation because the latter requires empirically motivated reasons in choosing how to group words for presentation (there are several different ways in which words may be sensibly grouped). Since the literature on comprehension of control structures with ditransitive verbs is scarce (with no studies with adults in European Portuguese), we reasoned that the "null model" of word-by-word presentation would be the best choice. Additionally, word-by-word presentation allows presenting sentences with relative clauses and sentences with control dependencies under the same conditions (in contrast to grouping, which could differentially affect parsing across control structures and relative clauses) and provides a maximally detailed picture of how the sentences are processed moment to moment.

The experiment was constructed and run using *PsychoPy* software (Peirce et al., 2019). All sentences were presented individually and occupied a single line on the center of the screen. Each trial started with a fixation cross presented at the center of the screen for 500ms, followed by a series of underscores indicating the number and length of all words in the sentence. Participants pressed the space bar to reveal each hidden word. When each word was revealed, the previous word reverted to underscores. Reading times at each word were measured as the time between key presses. Participants were asked to read attentively and at a natural pace. After reading each sentence, participants were shown a comprehension probe statement about the content of the sentence they had just read and were asked to press a *yes* key (signaled in green) if the statement was true and a *no* key (signaled in red) if the statement was false, as accurately and fast as possible. Accuracy and response times were also recorded. Comprehension probes were clefts that always targeted the critical dependencies in experimental sentences, i.e., resolution of the dependency between the antecedent (filler) and the empty position (gap). Clefts like (32) were used for sentences with relative clauses and clefts like (33) were used for sentences with control dependencies.

(32) O músico/pintor é que criticou o pintor/músico

the musician/painter is that criticized the painter/musician

‘It was the musician/painter that criticized the painter/musician’

(33) O músico/pintor é que vai escrever um livro

the musician/painter is that goes write a book

'It is the musician/painter that is going to the write a book

We used clefts instead of simpler sentences in order to avoid a potential problem with control conditions: most control sentences that we used do not provide sufficient information for the reader to know whether the entity corresponding to the controlled subject has performed/will perform the action described by the embedded verb. For instance, the sentence *The musician promised the painter to write a book* does not entail that the musician will actually write a book - he may have lied. Therefore, participants could have answered false to a true probe statement such as *The musician is going to write a book.* Cleft probes, such as *It is the musician that is going to write a book,* allow us to circumvent this problem by putting a DP in focus (i.e., *the musician*) and presupposing that the event described by the rest of the sentence is true (i.e., *someone is going to write a book*), therefore prompting participants to decide which DP functions as the subject of the embedded clause, which is precisely what we aim to assess. Since only subject clefts (not object clefts) were used to test accuracy, no intervention effects are expected in the comprehension of the cleft probe itself.

One potential limitation of probing only for understanding of the critical dependency is that in the relative clause conditions, participants could pay attention only to the first part of the sentence, containing the relative clause, and still achieve high accuracy. However, we think that it is unlikely that participants adopted this strategy, since (i) sentences containing relative clauses were randomly presented amongst different kinds of complex sentences, which would prevent participants from paying too much selective attention to relative clauses; (ii) one type of filler sentences (34), which included temporal clauses, described a relation between two NPs in the first part of the sentence, just like sentences containing relative clauses, but required processing the whole sentence in order to answer correctly to the comprehension probe (35).

(34) A Laura despediu a Helena quando foi ao escritório
the Laura fired the Helena when went PREP.the office
'Laura fired Helen, when she went to the office'

(35) A Laura é que foi ao escritório
the laura is that went PREP.the office
'It was Laura that went to the office'

For each sentence, a true and a false probe statement were constructed to control for potential response bias. Each participant saw only one comprehension probe per sentence and all participants saw an equal number of true and false probes.

Before the experiment began, participants performed four practice trials to get familiar with the task. Following the practice trials, participants saw four blocks of 30 sentences, each with a similar number of sentences from each experimental condition. Within-block sentence presentation order was randomized for each participant and block presentation order was counterbalanced.

2.2.2. Supplementary tasks

In addition to the reading task, participants performed four supplementary tasks: (i) the Brown-Peterson task, providing an index of resistance to interference; (ii) the vocabulary subtest of the WAIS-III, as a proxy of verbal knowledge; (iii) the Reading Span, providing an index of working memory capacity; (iv) and the semantic fluency task, as a measure of lexical access ability.

Brown-Peterson task

The Brown-Peterson task measures resistance to proactive interference (PI). The task comprised three blocks. In each block, participants were presented with four lists of eight words. The first three lists consisted of exemplars taken from the same semantic category (mammals, countries or body parts), building up interference, whereas the fourth list consisted of exemplars taken from a different category (clothes, fruits or types of dwellings), allowing a release from interference. The words used in the lists were taken from the Portuguese category norms in Pinto (1992) (for a complete list of the words used in this task, see Appendix II). Words in each category were ranked below the 12 strongest associates to the category and had at most 10 letters, following Kane and Engle (2000).

The task began with a fixation cross displayed on the center of the screen for 2 seconds, followed by a list of eight words, presented word-by-word on the center of the screen at the rate of 2 seconds (1750ms for stimulus presentation + 250 for interstimulus interval). Participants read each word aloud. After seeing a complete list, participants performed a distractor task: a letter-number pair (e.g., B-20) typed in blue appeared on the center of the screen and participants immediately read aloud the letter-number pair and named the subsequent pairs according to the alpha-numeric sequence, as fast and accurately as possible (e.g., if presented with the pair B-20, participants should say: B-20, C-21, D-22, E-23,…). After 16 seconds, a black screen with two question marks (*??*) cued participants to orally recall the words from the list they saw. They had 20 seconds to recall as many words as they could, in any order. When the recall period was over, a screen with the phrase *Terminou o tempo* ‘The time is up' appeared for 2 seconds, after which the sequence described above was repeated, starting with the fixation cross (indicating an upcoming list of words). Participants had 15 seconds to rest between blocks.

Block and interference build-up list presentation order were randomized for each participant. Presentation and timing of stimuli were controlled using *E-Prime* software (www.psnet.com).

The dependent measure was the mean proportional interference effect, calculated for each participant by subtracting the mean recall on List 3 from the mean recall on List 1 and dividing the remainder by the mean recall on List 1 (similarly to Kane & Engle, 2000). Higher scores indicate lower capacity to resist interference.

Vocabulary subtest (WAIS-III)

We used the vocabulary subtest of the WAIS-III (Barreto, Moreira & Ferreira, 2008) as a measure of verbal knowledge. Participants were asked to provide definitions for up to 33 words. We followed the administration and scoring criteria provided in the WAIS-III manual. Each answer received a score of 0, 1 or 2, where *0* indicates a clearly incorrect answer, *1* indicates an answer which, though not incorrect, reveals poverty in content, and *2* indicates an answer that reflects good understanding of the meaning of the word. The dependent measure was the total score in the test, summed across the 33 words, with higher scores denoting more extensive verbal knowledge.

Reading Span

The Reading Span task was used to obtain an index of working memory capacity. Participants were required to remember letters while performing a reading task, based on Kane et al. (2004). Participants were shown Power-point slides containing a single sentence followed by a question mark and a to-be-remembered letter (e.g., *A camisola branca fica-lhe larga, mas a preta fica-lhe provável* ‘The white sweater is loose on him, but the black one is probable’ *? X*), centered onscreen. Each sentence consisted of 10-15 words, was unrelated to the others, and could be either understandable or nonsensical (for a complete list of the sentences, see Appendix III). Nonsensical sentences were rendered nonsensical by a semantically or pragmatically incongruent word (e.g., *probable* in the example above), which could appear equally often in the beginning, middle and end of the sentence. There was an equal number of understandable and nonsensical sentences. The letters used were *B*, *L*, *J*, *F*, *X*, *Q*, *M*, *R*, *H*, following Kane and colleagues (2004). These letters were chosen because their names are phonologically distinct from each other. Each letter appeared an equal number of times in the experiment and no more than once in each trial.

When participants were shown a slide containing a sentence, they immediately started reading aloud. After reading the sentence, they verified aloud whether it made sense, by saying *yes* if it made sense and *no* if it did not. The question mark was included in the display to remind participants to give their answer. Finally, they read aloud the letter and the experimenter switched slides. Each trial consisted of a set of two to five sentence-letter problems. After seeing all the sentence-letter problems in a set, participants saw a recall cue (black screen with two question marks), indicating that they should write all the letters seen in the current trial in a response sheet, in the order that they appeared.

There were three trials for each set size (2-5), for a total of twelve trials. Set presentation order was randomized once.

The dependent measure was the mean proportion of correctly recalled elements (letter and position) per trial (Conway et al., 2005). Higher scores reflect greater working memory capacity.

Semantic fluency task

To measure lexical access ability, we used the semantic fluency task. Participants were given a semantic category (e.g., supermarket items) and were asked to name as many exemplars of that category as possible in 60 seconds. There were two semantic categories, *supermarket items* and *vegetables*. The dependent measure was the mean number of productions, excluding errors and repetitions (Troyer, 1997). When a subcategory (e.g., fish) was produced along with specific members of that category (e.g., salmon, swordfish, monkfish), only the specific exemplars (salmon, swordfish, monkfish) were counted, following Troyer & Moscovitch (2006).

Data from three participants was discarded due to an error in the recording of their responses.

2.3. Data Analysis

As mentioned above, the dependent measures obtained from the sentence comprehension task included accuracy, response time and reading times. The analyses of response time and reading times were restricted to correct trials. Response times that were more than 3 standard deviations away from the mean of each condition, by participant, were excluded (affecting 0,4% of the data). Reading times that were more than 3 standard deviations away from the mean of each word position, by condition and participant, were removed, and multi-word regions including removed words were excluded from the analysis (affecting 0,7-2,2% of the data, depending on region). This procedure was carried out in order to remove data that likely reflect processes unrelated to normal task performance (e.g., distraction and mind-wandering). Response times and reading times were log-transformed to improve the normality of the residuals (so as to conform with the assumptions of the general linear model, Baayen & Milin, 2010).

The data were analyzed using Mixed effects models (Baayen, Davidson & Bates, 2008; Locker, Hoffman & Bovaird, 2007), constructed in SPSS 25. For the analysis of accuracy, a logit link function was used (Jaeger, 2008). Mixed models have been broadly adopted in the Psycholinguistic literature. One advantage of these models over traditional ANOVAs is that they allow for crossed random factors of participants and items and thus eliminate the need to conduct separate by-subject (F1) and by-item (F2) analyses (which are recommended in the ANOVA framework to generalize the findings to different samples of subjects and items). Furthermore, they are more powerful than standard ANOVAs (Baayen, Davidson & Bates, 2008), are more tolerant to missing data (Locker, Hoffman & Bovaird, 2007), and allow for adequate modeling of interactions between individual differences (e.g., in working memory capacity) and text-level variables (e.g., syntax) (Blozis & Traxler, 2007).

We constructed global models, which included all the syntactic conditions (i.e., SR, OR, SC and OC), and separate models for the relative clause conditions and for the control conditions (described in detail in section 3). The global models included two independent variables from the sentence comprehension task: the syntactic variable *Structure type* (*Control*; *Relative clause*), and the syntactic variable *Structure subtype* (*Subject*; *Object*). In the analysis of accuracy, an additional independent variable was included: the task variable *Expected answer* to the comprehension probe (*True*; *False*), which was included in the analysis to probe for response bias in our sample, since it may interfere in the estimation of the effects of syntactic variables. The models for relative clause conditions and control conditions included one independent variable from the sentence comprehension task: the syntactic variable *Structure subtype* (*Subject*; *Object*).

We constructed simple models, in which only variables from the sentence comprehension task were included, and full models, in which both variables from the sentence comprehension task and individual differences in supplementary tasks (i.e. Brown-Peterson task; vocabulary subtest (WAIS-III); Reading Span; and semantic fluency task) were included, all entered as fixed effects. Continuous independent variables (covariates) were mean centered prior to analysis. Hence, significant effects of syntactic variables in models that include individual differences in supplementary tasks indicate effects of syntax when performance in the supplementary tasks is at the mean.

Participants and items were entered as random effects wherever possible.

3. Results

We first report the results obtained with the simple models, which assessed the effects of the syntactic manipulations on accuracy, response time and reading times of the sentence comprehension task (section 3.1). Then, we report the findings of the full models, which informed whether individual differences in performance in the Brown-Peterson task, vocabulary subtest, Reading Span and semantic fluency task modulated the syntactic effects (section 3.2).

3.1. Sentence comprehension task

3.1.1. Accuracy

Overall, accuracy was high (*M* = 88%, *SD* = 7,7%, across experimental items and fillers), indicating that participants performed the task attentively. Figure 5 shows the mean proportion of correct answers per condition.

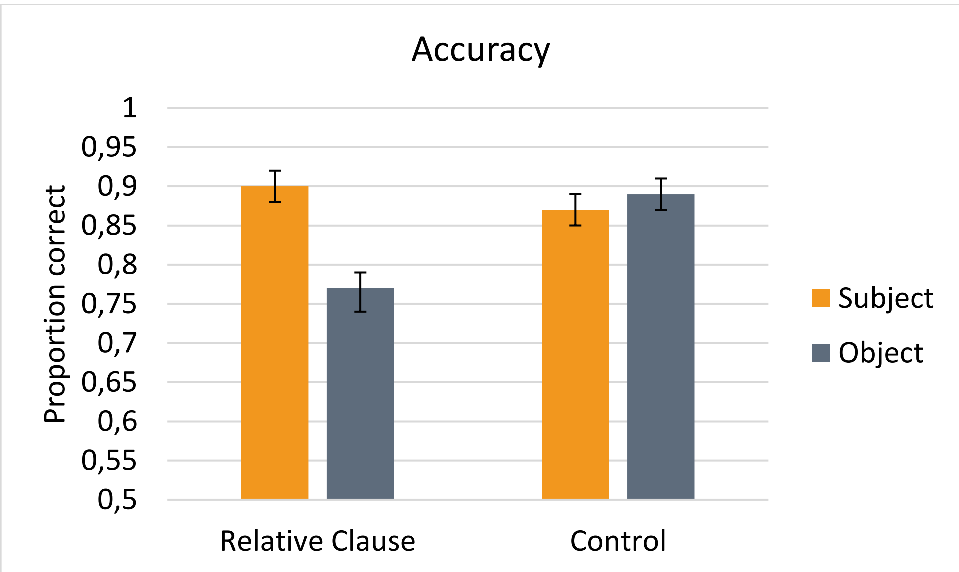

Figure 5. Mean proportion of correct responses per condition (bars represent 95% confidence interval).

We tested whether the difference in accuracy, commonly found between SR and OR, also occurs in control structures. The statistical model included accuracy as the dependent variable and as fixed effects the syntactic variables *Structure type* (*Relative clause; Control*) and *Structure subtype* (*Subject*; *Object*) and, critically, the interaction between them. The model also included the main effect of *Expected answer* to the comprehension probe (*True*; *False*) and all possible interactions with the remaining variables.

Accuracy was not significantly different as a function of the expected answer to the comprehension probe, $F(1, 4132) = 3.46$, $p = .063$. Importantly, the triple interaction between *Structure type*, *Structure subtype* and *Expected answer* to the comprehension probe was also not significant, $F(1, 4132) = .026$, $p = .871$. These results suggest that response bias was negligible and did not interfere with the syntactic variables. Therefore, we did not include the effect of *Expected Answer* to the comprehension probe in any other model.

The critical interaction between *Structure type* and *Structure subtype* was significant, $F(1, 4132) = 29.72$, $p < .001$. Pairwise Sidak-corrected contrasts showed that whereas accuracy for SR was significantly greater than for OR, $t(4132) = 6.024$, $p < .001$. , there was no difference between SC and OC, $t(4132) = -1{,}336$, $p = .182$.

Since the properties of the control verbs were not controlled for (e.g., frequency), due to there being a limited number of subject control verbs in European Portuguese, we conducted two post-hoc analyses, one only with SC sentences and another only with OC sentences, to assess whether accuracy changed as a function of the control verb used in the sentence – it could be that some verbs were more representative of their category than others. Results for the SC condition[21] revealed a significant main effect of control verb, $F(4, 1030) = 7.61$, $p < .001$. Pairwise Sidak-corrected comparisons indicated that the SC verb *ameaçar* 'threaten'

[21] The model failed to converge with random effects of subjects and items. Therefore, we included only random effects of subjects.

differed from all other subject control verbs (see Table 1 and Figure 6). No other comparison emerged as statistically significant. Results for the OC condition revealed no significant main effect of control verb, $F(4, 1030) = 1.178$, $p = .319$. These findings suggest that control structures with *ameaçar* were processed atypically. Therefore, we excluded all such sentences from the remaining analyses.

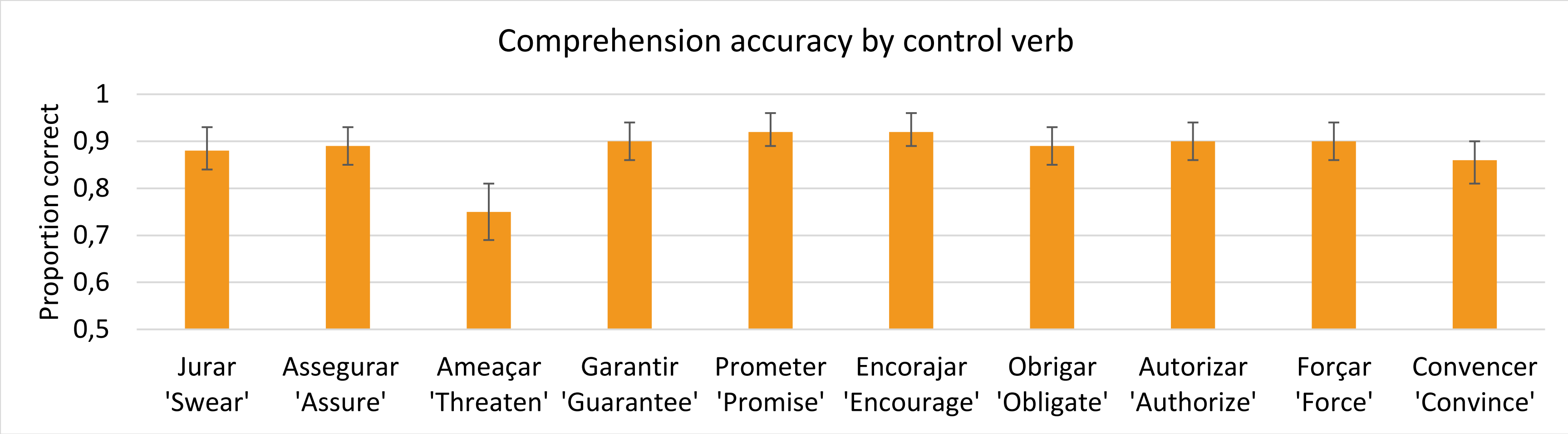

Figure 6. Mean proportion of correct responses by control verb (bars represent 95% confidence interval).

Contrast	t-statistic	df	p-value
Jurar - Assegurar	-.16	1030	.951
Jurar - Ameaçar	3.48	1030	.004
Jurar - Garantir	-.48	1030	.951
Jurar - Prometer	-1.34	1030	.701
Assegurar - Ameaçar	3.63	1030	.002
Assegurar - Garantir	-.32	1030	.951
Assegurar - Prometer	-1.18	1030	.743
Ameaçar - Garantir	-3.93	1030	.001
Ameaçar - Prometer	-4.71	1030	<.001
Garantir - Prometer	-.86	1030	.859

Table 1. Pairwise Sidak-corrected contrasts for subject control verbs.

3.1.2. Response time

Figure 7 shows the mean response time to the comprehension probe per condition.

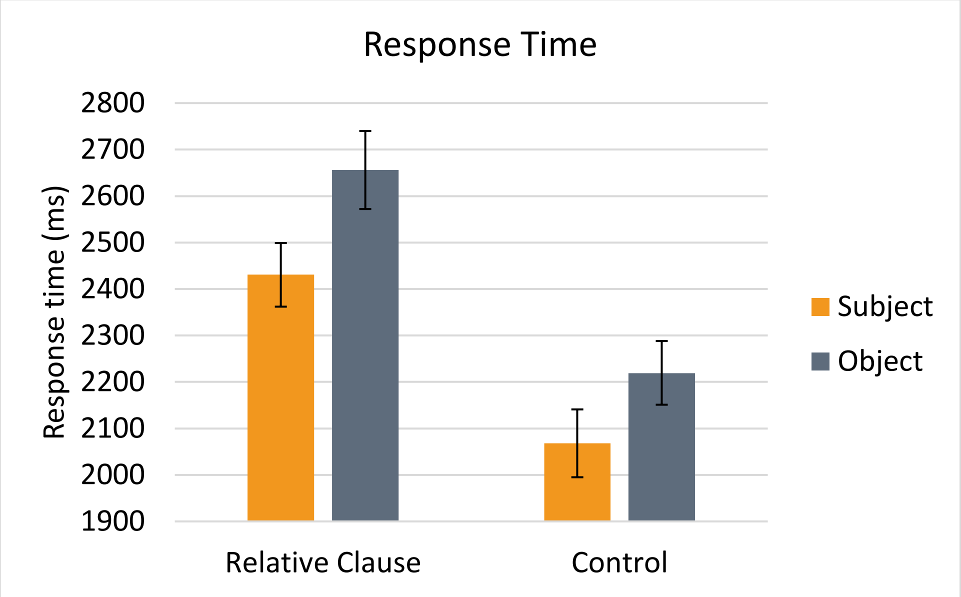

Figure 7. Mean response time by condition (bars represent 95% confidence interval).

This analysis aimed to assess whether the predicted difference between SR and OR is paralleled in control structures. The statistical model included response time as the dependent variable and included as fixed effects the syntactic variables *Structure type* (*Relative clause; Control*) and *Structure subtype* (*Subject*; *Object*) and the interaction between them. Sentences containing *ameaçar* were excluded from the analysis. The results showed that the interaction between *Structure type* and *Structure subtype* was not significant, $F(1, 3379) = .082$, $p = .774$. Pairwise Sidak-corrected contrasts showed that the difference in response time between SR and OR was significant, $t(3379) = -3{,}46$, $p < .001$, with longer response times for OR, and that the difference in response time between SC and OC was also significant, $t(3379) = -2{,}94$, $p = .003$, with longer response times for OC. The non-significant interaction indicates that these differences did not differ.

3.1.3. Reading times

Figure 8 and Figure 9 show the mean reading times per word for relative clause conditions and control conditions, respectively.

Figure 8. Mean reading times per word for SR and OR conditions.

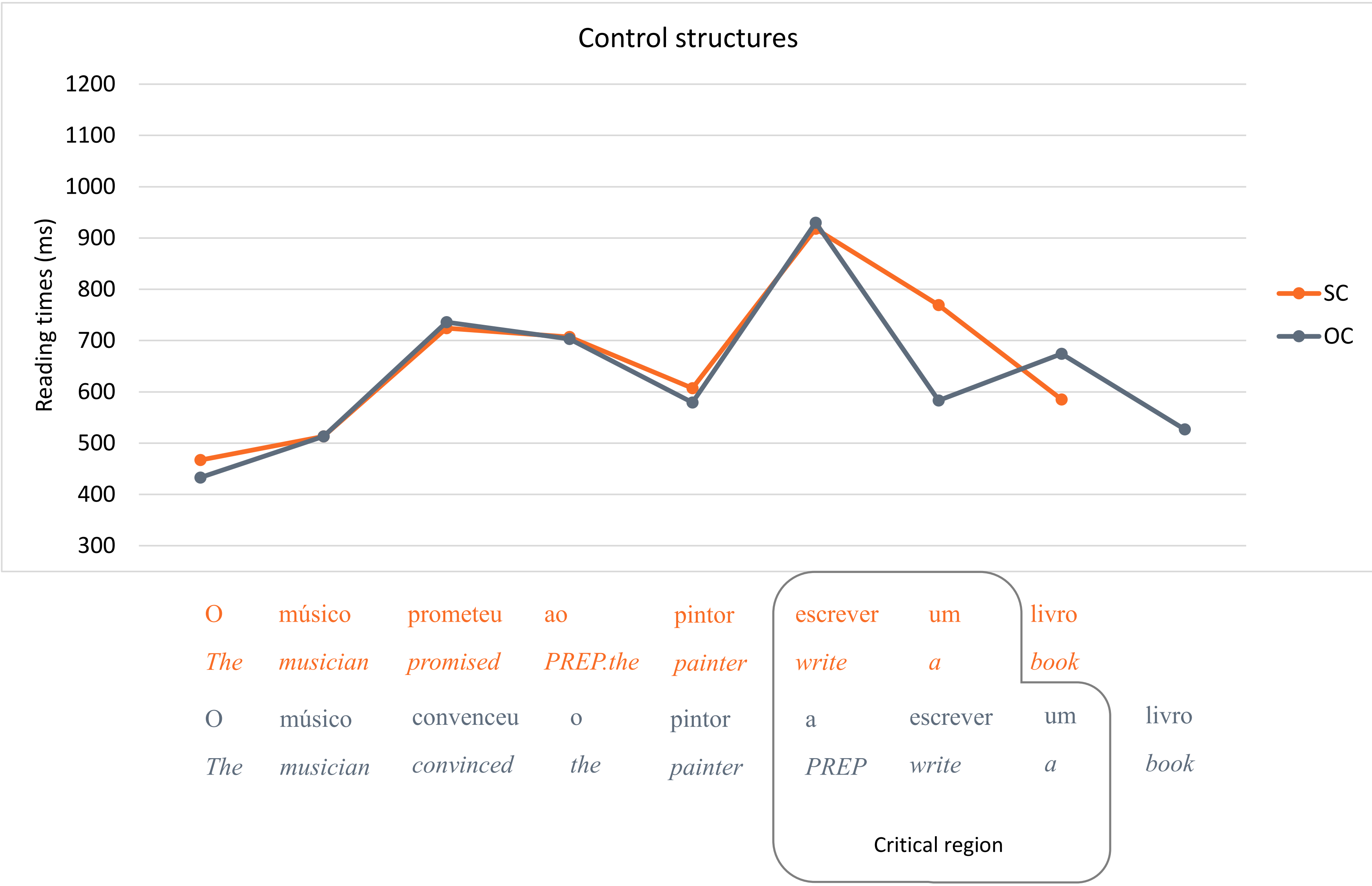

Figure 9. Mean reading times per word for SC and OC conditions.

This analysis tested how the critical dependencies are resolved online. We constructed separate models for relative clause conditions and control conditions, since their sentence structures necessarily differed. The models tested for the significance of the effect of *Structure subtype* (*Subject*; *Object*). As in the previous analyses, we excluded sentences with *ameaçar*. The dependent variable was the average reading time per word at a given region of interest.

For the relative clause conditions, we defined two regions of interest:

1. The *critical region* was defined as the last three words of the relative clause. Even though resolution of the critical dependency is expected to occur at the embedded verb, which contains an empty argument position, a direct comparison between the two embedded verbs would be hard to interpret, since the embedded verb in OR appears at a position that corresponds to the end of the relative clause and where both its subject and its object were already seen, whereas the embedded verb of SR does not; hence, a difference in gap type (subject vs object) is potentially confounded with processing differences related to position. The relative clause region (the complementizer was omitted because it is the same in SR and OR) contains the same words, only in a different order, thus allowing for a more straightforward contrast between SR and OR processing.

2. The *post-critical region* was defined as the two words that follow the relative clause region, the main verb and the determinant from the last DP, in which there may still be processing related to the resolution of the filler-gap dependency (i.e., spillover effect, Just, Carpenter & Wolley, 1982). The noun from the last DP was not included because reading times at the last word may reflect processes related to revision of the whole sentence (i.e., *wrap-up effects*, Just and Carpenter, 1980).

For the control conditions, we defined one region of interest:

1. The *critical region* was defined as the last two words in SC (Embedded verb + Determiner from DP3) and the last three words in OC (preposition *a* + embedded verb +

determiner from the last DP). Analysis of this region aimed to assess whether the resolution of the critical control dependency differs between SC and OC. Resolution of the control dependency requires association of a DP with the empty position at the subject position of the complement clause, which must then be integrated with the verb. Although the empty position is assumed to occur adjacent to the embedded verb position in both SC and OC sentences, a direct comparison between these two words would suffer from interpretability issues. In OC sentences, the preposition that occurs before the embedded verb (which is absent in SC sentences, excluding those with *ameaçar*) unambiguously informs the parser that an empty position is coming next: from the preposition, the embedded verb necessarily follows. In SC sentences, on the other hand, the parser does not know where the empty position is until reaching the embedded verb position (since the noun that precedes the embedded verb is modifiable, e.g., instead of *O músico prometeu ao pintor escrever um livro* ‘ the musician promised the painter to write a book’, one could have e.g., *O músico prometeu ao pintor que insultou o poeta escrever um livro* ‘The musician promised the painter who insulted the poet to write a book’). It is reasonable to assume, then, that assignment of a DP as controller of the empty position may initiate at the preposition in OC (the first region of direct evidence for the empty position) and at the embedded verb in SC. If this is on the right track, then reading times at the embedded verb region may reflect different processes in SC and OC sentences. A direct comparison of the preposition in OC and the embedded verb in SC would also be potentially problematic, since (i) we would be comparing words corresponding to different grammatical categories; (ii) reading times at the embedded verb position may reflect not just resolution of the control dependency, but also integration of the subject with the verb. We therefore took the whole complement clause (excluding the last noun, due to potential wrap-up effects), including the preposition in OC, as the critical region, containing all positions in which there may be processing related to resolution of the control dependency and integration of the empty position with the verb (including post-verbal regions, where there may be spillover effects, Just, Carpenter and Woolley, 1982). Even though we argue that this contrast is more justified than a direct comparison between embedded verbs, the extra word in OC sentences (i.e., preposition) still renders interpretation complicated. We return to this point in the discussion.

The analysis of relative clause conditions showed that reading times in the critical region were not significantly different between SR and OR sentences, $F(1, 1689) = .51$, $p = .475$. However, there was a significant difference in the post-critical region, $F(1, 1706) = 48.98$, $p < .001$, with slower times for OR than for SR (see Figure 8 above).

The model for control conditions revealed significant differences in the critical region, $F(1, 1639) = 65.31$, $p < .001$, with longer reading times for SC sentences than for OC sentences (see Figure 9 above).

3.1.4 Summary

Regarding responses to the comprehension probe, we found an asymmetry in accuracy between SR and OR, with worse performance for OR, but no asymmetry between SC and OC. As for the response times to the probe, there was an asymmetry between SR and OR, with longer times for OR, and a similar asymmetry between SC and OC, with longer times for OC than SC. Finally, for reading times, we found an asymmetry between SR and OR in the post-critical region (i.e., spillover region), with longer times for OR, and an asymmetry between SC and OC in the critical region, with longer times for SC.

3.2. Individual differences in sentence comprehension

The full models tested whether the effects investigated in the previous section were modulated by performance on the supplementary tasks. The full models were constructed from the simple models by adding terms for main effects of performance in the supplementary tasks (i.e., covariates: Brown-Peterson task, vocabulary subtest (WAIS-III), Reading Span, and semantic fluency task) and terms for interactions between each supplementary task and each syntactic variable.

Since all covariates were always included, the models tested for the effect of each covariate while controlling for the effects of the other covariates (i.e., unique effect). As before, sentences with *ameaçar* were excluded from all analyses.

All effects found with simple models were replicated with the full models. Hence, we report only main effects of covariates and interactions with covariates.

3.2.1 Supplementary tasks (covariates)

Figure 10 shows the mean performance on the Brown-Peterson task.

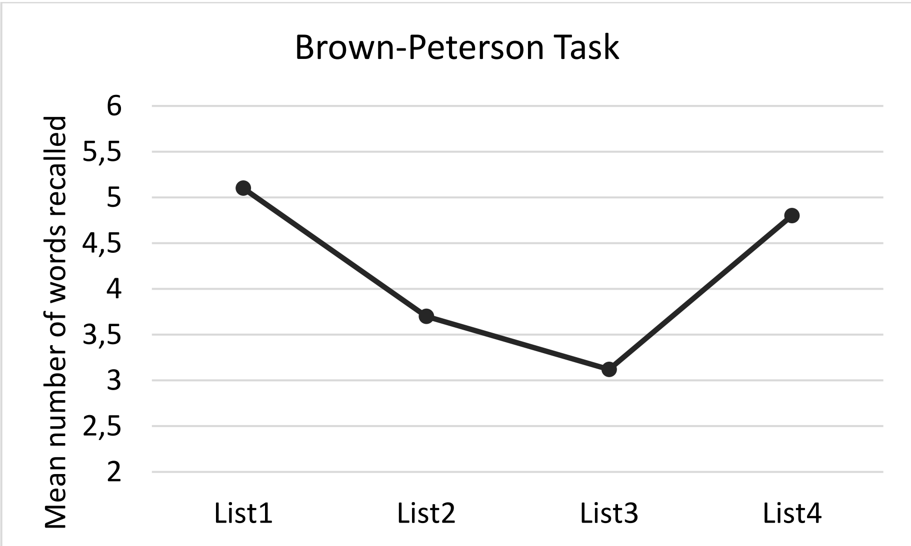

Figure 10. Mean number of words recalled per list in the Brown-Peterson task.

Performance on the Brown-Peterson task decreased from List 1 to List 2 and from List 2 to List 3, evidencing interference buildup, and increased from List 3 to List 4, evidencing release from interference. This replicates previous research (e.g., Kane & Engle, 2000; Friedman & Myiake, 2004) and indicates that performance on the Brown-Peterson task was sensitive to similarity-interference, as predicted.

Table 2 presents the overall mean scores, standard deviations and range found in all supplementary tasks.[22] Table 3 presents bivariate Pearson correlations between the measures.

Task	Mean	SD	Range	Max. Score
Brown-Peterson task	.37	.19	-.22 - .85	1
Vocabulary subtest	47.05	6.4	34 – 60	66
Reading Span	.62	.13	.25 - .95	1
Semantic fluency task	13.13	4.19	5 – 28.5	

Table 2. Descriptive statistics for the supplementary tasks.

[22] The minimum value in the Brown-Peterson task deserves a note. Theoretically, participants should not have negative scores, since our dependent measure ((List3-List1)/List1) is presumed to index susceptibility to interference (one cannot be negatively susceptible to interference). Negative scores reflect facilitation across the task, which runs contrary to our expectations, and are thus potentially problematic. However, we note that only one participant had a negative score. Since there was only one negative score, and the group performance was expected, we see no reason to question the validity of our task.

Task	Brown-Peterson task	Vocabulary subtest	Reading Span	Semantic fluency task
Brown-Peterson task				
Vocabulary subtest	-.117			
Reading Span	-.259*	.202		
Semantic fluency task	-.346**	.290*	.160	

Table 3. Bivariate Pearson correlations between the supplementary tasks.

*. significant at the .05 level; **. significant at the .01 level

The Brown-Peterson task showed a weak, yet significant negative correlation with Reading Span (r = -.259, p < .05), consistent with prior work and theoretical models that postulate an attention component in working memory capacity which guards processing against interference (Borella, Carretti & Mammarella, 2006, Engle & Kane, 2004; Unsworth, 2010). The semantic fluency task was significantly correlated with both the vocabulary subtest (r = .290, p < .05) and the Brown-Peterson task (r = -.346, p < .01), suggesting that semantic fluency is associated with lexical knowledge as well as with the ability to resist interference (Rosen & Engle, 1997).

Since all correlations were modest, with no correlation stronger than (r = -.346), there was no evidence for multicollinearity between our measures.

3.2.2 Accuracy

The model for accuracy included the syntactic effects of *Structure type*, *Structure subtype* and their interaction, as well as main effects of covariates and all possible interactions with the syntactic effects. The results showed a significant main effect of Reading Span, F(1,

3742) = 19.25, p < .001, indicating that better performance in the Reading Span task was associated with greater accuracy. No triple interaction (i.e., between *Structure type*, *Structure subtype* and covariate) reached significance.

Since the complexity of our model, which included several triple interactions, could have potentially concealed otherwise significant effects, we also constructed separate models for relative clause conditions and control conditions. These models included the syntactic effect of *Structure subtype*, as well as main effects of covariates and all possible interactions with *Structure subtype*.

The model for relative clause conditions revealed only a main effect of Reading Span, $F(1, 1970) = 16.86$, p < .001, indicating that accuracy with relative clauses increased as a function of participants' Reading Span abilities (see Figure 11[23]).

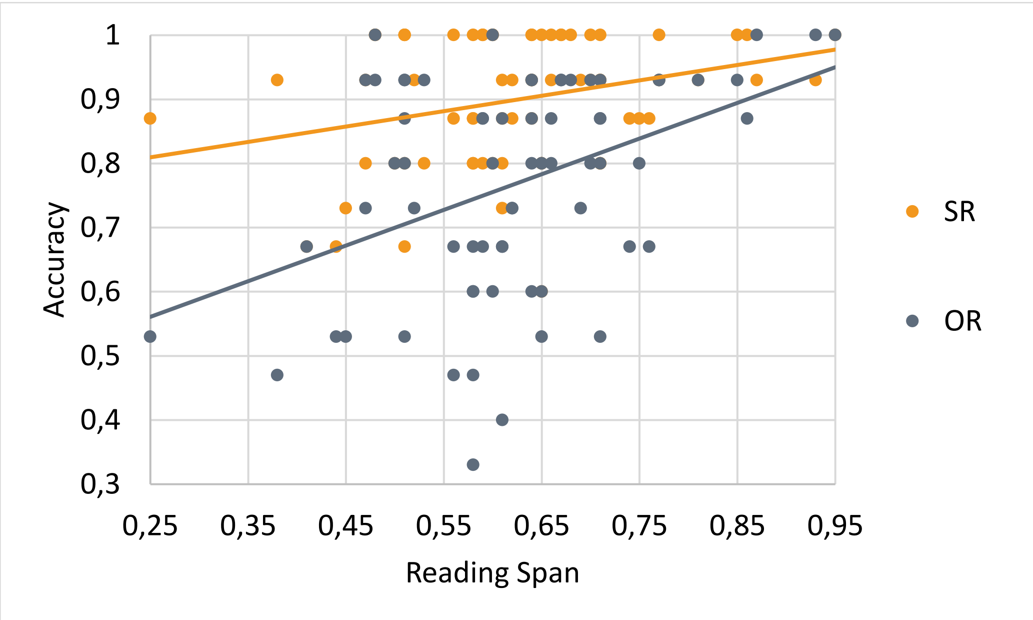

Figure 11. Correlation between Reading Span and accuracy in relative clause conditions.

[23] The difference in steepness of the slopes in Figure 1 suggests a significant interaction between relative clause type and Reading Span. Such an interaction was not found. However, it is important to note that, as previously described, the model tested for an association between Reading Span and relative clause type after controlling for (i.e. removing variability shared with) the other covariates (i.e. Brown-Peterson task, vocabulary subtest and Semantic fluency task.).

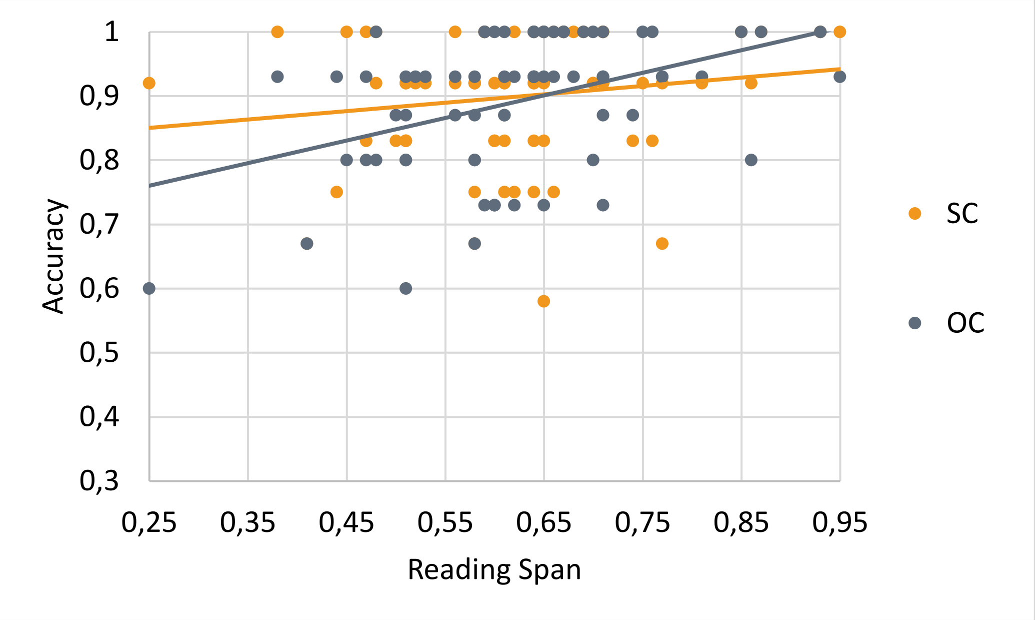

Figure 12. Correlation between Reading Span and accuracy in control conditions.

For the control conditions, there was a significant main effect of Reading Span, *F*(1, 1772) = 8.68, *p* < .003, indicating that accuracy for control sentences increased as Reading Span abilities increased (see Figure 12). There was also a marginally significant interaction between Reading Span and *Structure subtype*, *F*(1, 1772) = 3.80, *p* = .052. As seen in Figure 12, Reading Span had a stronger effect on the accuracy of OC than SC sentences.

3.2.3. Response time

The model for response time included the syntactic effects of *Structure type*, *Structure subtype* and their interaction, as well as main effects of covariates and all possible interactions with syntactic variables. The analysis revealed no significant main effects of covariates nor significant triple interactions (i.e., between *Structure type*, *Structure subtype* and covariate). As in the analysis of accuracy, we also constructed separate models for relative clause and control conditions.

Only the model for relative clause conditions revealed a significant effect: interaction between *Structure subtype* and Reading Span, $F(1, 1645) = 5.37$, $p = .021$. As illustrated in Figure 13, this interaction reflected a stronger negative association between Reading Span and response time for OR than for SR sentences.

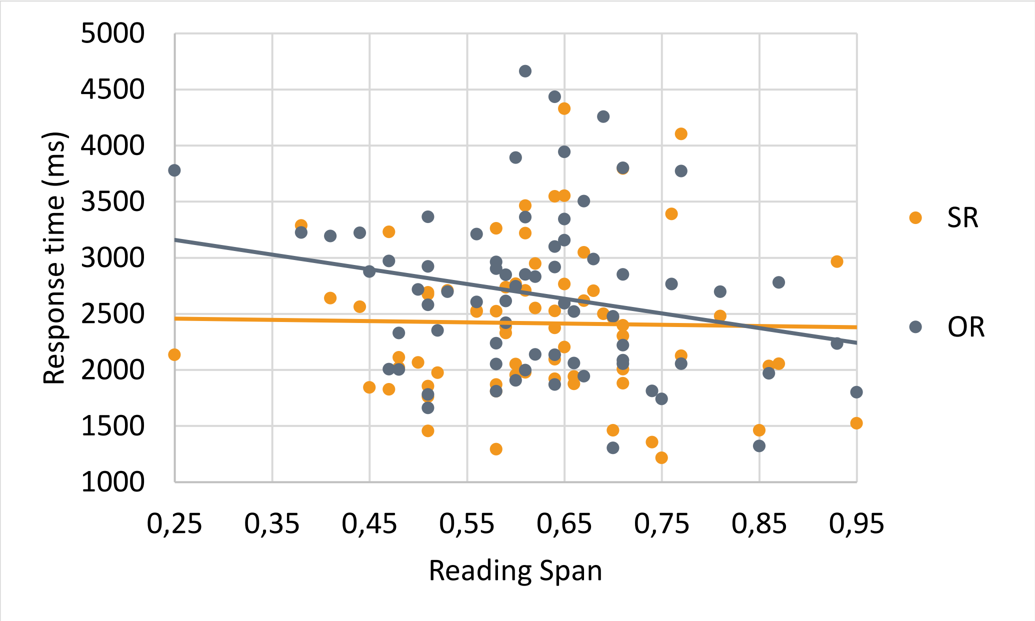

Figure 13. Correlation between Reading Span and response time in relative clause conditions.

3.2.4. Reading times

Models for the analyses of reading times were constructed separately for relative clause conditions (critical region and spillover region) and control conditions (critical region), as before, including the syntactic variable of *Structure subtype*, as well as main effects of covariates and interactions with Structure subtype.

For the relative clause conditions, we found a main effect of the Brown-Peterson task in the critical region, $F(1, 1616) = 4.66$, $p = .031$, denoting that participants with better scores in the Brown-Peterson task read sentences with relative clauses faster (see Figure 14).

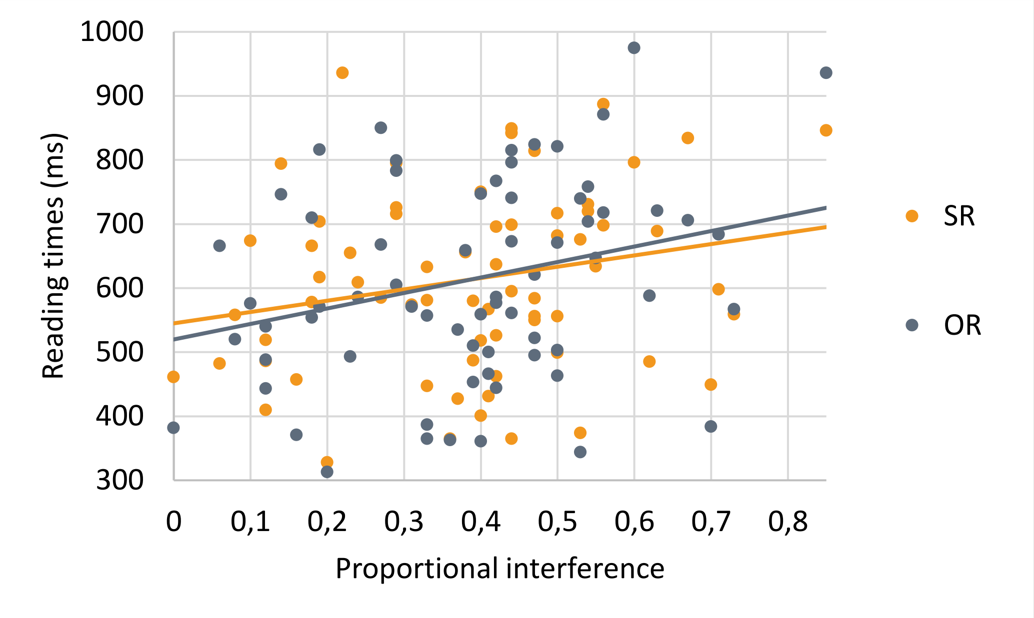

Figure 14. Correlation between reading times at the critical region of relative clause conditions and performance on the Brown-Peterson task (higher values represent worse performance).

In this region, there were also significant interactions between *Structure subtype* and the Brown-Peterson task, $F(1, 1616) = 4.69$, $p = .030$, vocabulary subtest, $F(1, 1616) = 4.05$, $p = .044$, and Reading Span, $F(1, 1616) = 5.71$, $p = .017$. Performance on the Brown-Peterson task had a stronger effect on OR than on SR reading times (see Figure 14), with better performance on the Brown-Peterson task associated with shorter reading times. On the other hand, performance on the vocabulary subtest (Figure 15) and Reading Span (Figure 16) had a stronger effect in SR than OR reading times, with better performance on these tasks associated with shorter reading times.

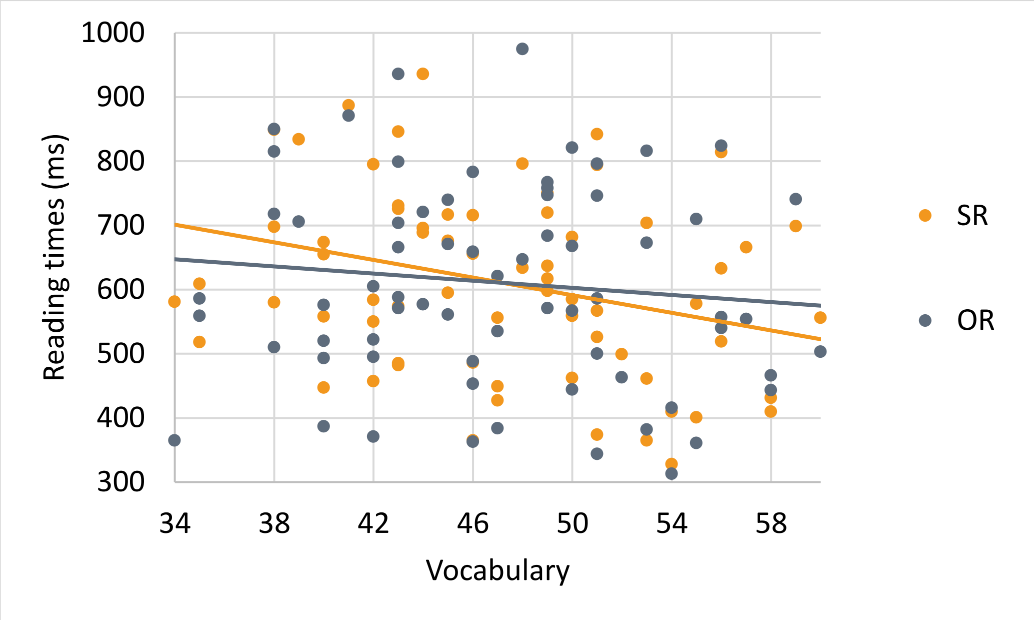

Figure 15. Correlation between reading times at the critical region of relative clause conditions and performance on the vocabulary subtest.

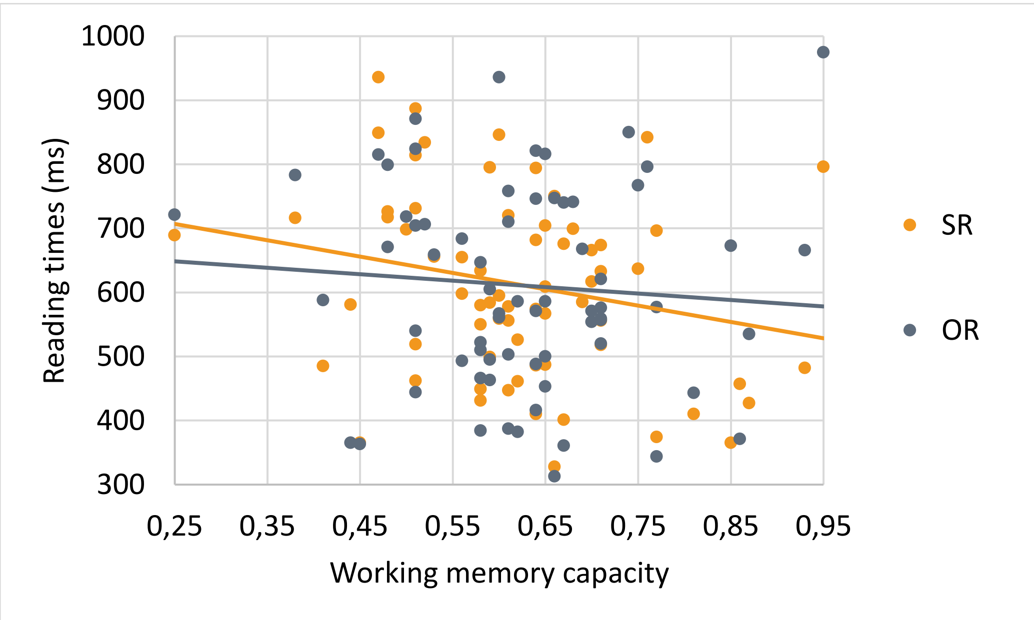

Figure 16. Correlation between reading times at the critical region of relative clause conditions and performance on the Reading Span task.

In the post-critical region[24], there was a significant main effect of the Brown-Peterson task, $F(1, 1632) = 5.35$, $p = .021$, revealing that participants with better performance on the Brown-Peterson task read relative clause sentences faster (see Figure 17), and a significant main effect of Reading Span, $F(1, 1632) = 4.46$, $p = .035$, indicating that participants with better performance on the Reading Span read relative clause sentences slower. No interactions reached significance in this region.

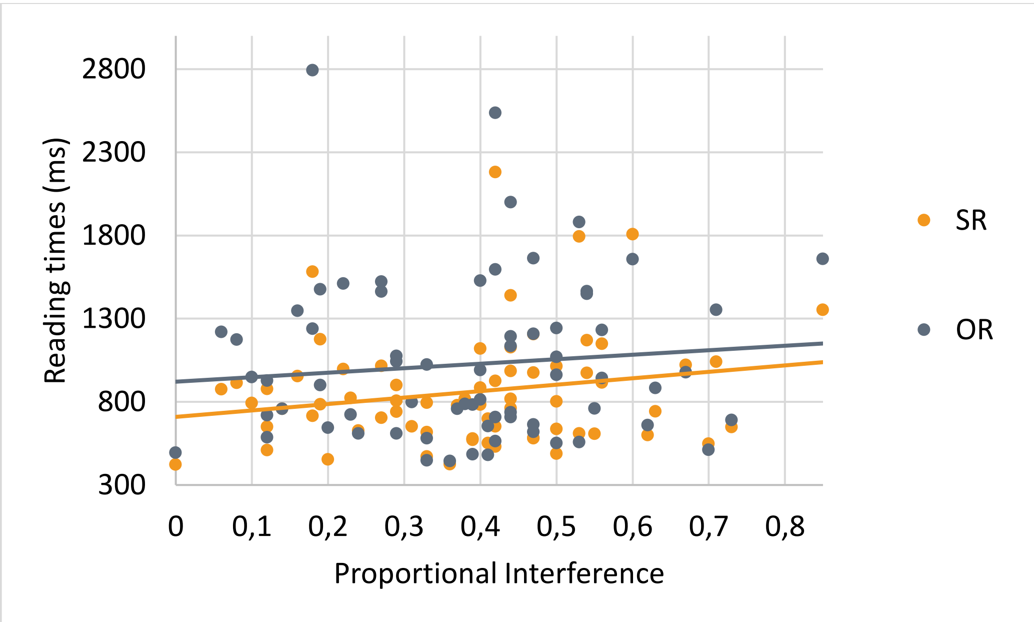

Figure 17. Correlation between reading times at the post-critical region of relative clause conditions and performance on the Brown-Peterson task (higher values represent worse performance).

[24] The model did not converge with random effects of subjects and items. Hence, only subjects were included as random effect.

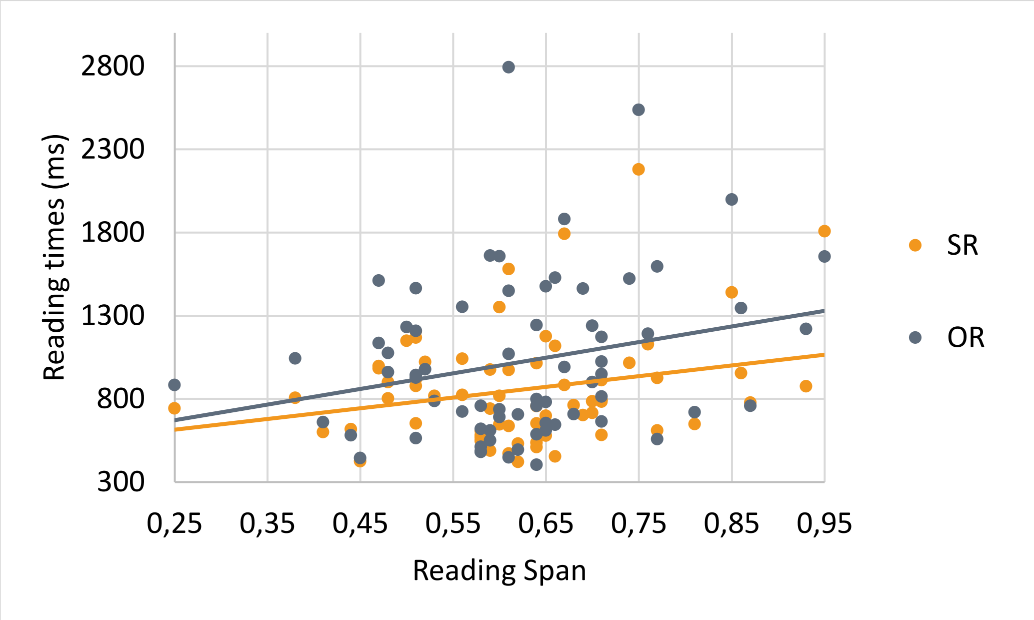

Figure 18. Correlation between reading times at the post-critical region of relative clause conditions and performance on the Reading Span task.

For the control conditions, we found a significant main effect of the Brown-Peterson task in the critical region, $F(1, 1566) = 9.48$, $p = .002$, indicating that participants with better performance on the Brown-Peterson task (i.e., lower scores) read control sentences faster (see Figure 19). No interactions reached significance.

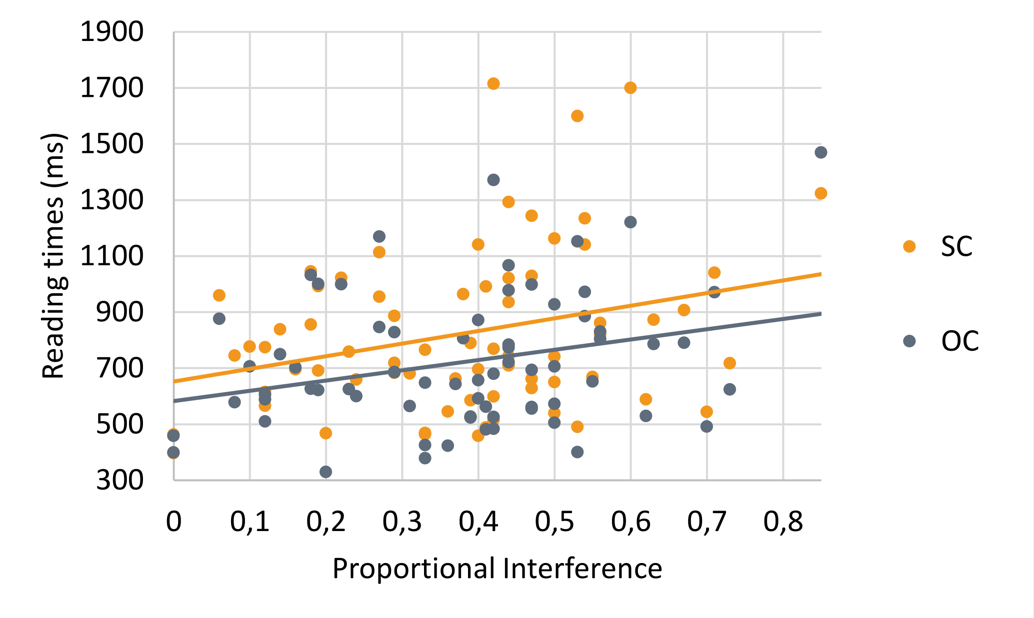

Figure 19. Correlation between reading times at critical region of control conditions and performance on the Brown-Peterson task (higher values represent worse performance).

3.2.5. Summary

Better performance on Reading Span was associated with higher overall accuracy. Furthermore, the relationship between Reading Span and accuracy was stronger on OC than on SC, suggesting that greater Reading Span skill was associated with higher accuracy particularly for OC.

For response time, we found a stronger effect of Reading Span on OR than on SR, indicating that greater Reading Span skill was associated with faster response times especially for OR.

As for reading times, we found that better performance on the Brown-Peterson task was associated with shorter times in all regions assessed for relative clause and control conditions. The modulatory effect of the Brown-Peterson task was stronger for OR than SR in the critical region, suggesting that greater skill on the Brown-Peterson task was associated with shorter reading times especially for OR. Better performance on Reading Span correlated with longer reading times in the post-critical region of relative clauses. Furthermore, Reading Span had a stronger modulatory effect on SR than on OR in the critical region, indicating that greater Reading Span skill associated with shorter times particularly for SR. Finally, performance on the vocabulary subtest of WAIS-III had a stronger modulatory effect on SR than on OR in the critical region, suggesting that greater vocabulary was associated with shorter times especially for SR sentences.

4. Discussion

We will first discuss the results obtained with the simple models, which informed whether relative clauses and control structures revealed parallel asymmetries across individuals (section 4.1)*;* next, we discuss the results obtained with the full models, which examined how the supplementary tasks modulated the effects of syntax in relative clauses and control structures (section 4.2); then, we attempt to characterize the complexity effects of OR in light of our data (section 4.3); finally, we discuss implications of our results for Psycholinguistics, as well as some limitations of our work (section 4.4)

4.1. Sentence comprehension task

Results with relative clauses replicated previous research, showing complexity effects of OR both offline and online. Offline, we found that participants revealed lower accuracy and higher response times in answering comprehension probes about OR than about SR. Online, we found that OR were read more slowly than SR in the spillover region. These results indicate that our methodology was sound and provide a valid baseline against which we can compare processing of control.

Whereas results with relative clauses were consistent across all measures, evidencing that OR are harder to process than SR, results with control structures were not: (i) there was no difference between SC and OC in terms of accuracy in responding to the comprehension probes; (ii) Response times were longer for OC than SC, showing that participants need more time to respond correctly to comprehension questions related to OC sentences; and (iii) there were longer reading times for SC than OC at the critical region, indicating greater processing demands in reading SC sentences. Taken together, these results show that relative clauses and control structures do not reveal parallel complexity asymmetries (i.e. OR and SC do not induce similar complexity effects). This runs against memory theories predicting parallel asymmetries between relative clauses and control, namely the DLT (Gibson, 1998, 2000) and the cue-based parsing account (Lewis, Vasishth & Van Dyke, 2006) [25]. Adopting a grammatical framework of complexity effects, wherein complexity effects of OR are attributed to (hierarchical) intervention in the movement dependency (RM account, Friedmann, Belleti & Rizzi, 2009; Costa, Grillo & Lobo, 2013), our data lead to question an analysis of control as movement (Hornstein, 1999), which would predict parallel complexity effects in SC. A *smuggling* analysis of SC (Belleti & Rizzi, 2012), on the other hand, would not expect a parallel behavior in OR and SC, and is thus not inconsistent with our data.

Although we did not find consistent evidence for a processing asymmetry between SC and OC, we found evidence for greater difficulty with OC in response times and with SC in reading times. We will discuss these results in turn.

The longer response times to the probe question observed for OC were unexpected. Here, a suggestion put forward by Boland, Tanenhaus and Garnsey (1990) may prove relevant. On their view, OC may incur larger processing costs than SC due to a more complex semantic structure: whereas constructing an event structure of a SC verb requires representing a single *doer* involved in two related events, i.e., that denoted by the matrix verb and that denoted by the embedded verb, constructing an event structure of an OC verb requires representing two *doers*, one for each event, and an additional relationship, since the matrix subject is responsible for the event denoted by the embedded verb. Although this is an interesting possibility, it is not

[25] Cue-based parsing models predict that the difference in interference between SR and OR is larger than that between SC and OC (see 1.8 for detailed predictions). It could thus be argued that this difference in magnitude casts doubt on whether parallel complexity effects between SC and OR are expected, and that lower reading times with SC than with OC may reflect a small effect of interference which is not carried to offline measures. Although this possibility cannot be ruled out, there are reasons to believe that it is not justified. First, assuming cue-based parsing models, the mechanism assumed to cause potential complexity effects in SC and OR is the same, and it may therefore be expected to impact the same reading and comprehension measures in SC and OR, contrary to what we found. Second, and most importantly, this mechanism may be expected to specifically impact accuracy of SC, since interference may lead to incorrect retrieval of distractors (Van Dyke, 2007), contrary to what we found.

clear why greater semantic complexity of OC would not manifest itself in accuracy and, particularly, in reading times. These issues require further investigation.

The longer reading times with SC replicated previous research (Betancort, Carreiras & Acuña-Fariña, 2006), suggesting that there may be an early processing cost in parsing sentences involving SC dependencies. This result could be taken to support a *smuggling* analysis of SC (Belleti & Rizzi, 2012), since an asymmetry between SC and OC would be expected, though not necessarily parallel to that of relatives. However, it is not clear why difficulty with *smuggling* would manifest itself in reading times, but not in accuracy and response times. Moreover, as previously noted, the results for reading times should be interpreted with caution, due to the occurrence of an extra preposition in the critical region of OC sentences. Since the same processing steps (i.e., filling the empty position and integrating it with the verb) are distributed by a longer region, potential slowdowns for OC may be expected to dissipate.

4.2. Individual differences in sentence comprehension

Better performance on the Brown-Peterson task, indexing more capacity to resist interference, was correlated with shorter reading times for relative clauses and control structures in all regions analyzed. This main effect of resistance to interference may result from inter-trial interference in the self-paced reading task. That is, linguistic content from previous trials (e.g., NPs) may still be accessible in participants' memory, conflicting with the current trial. If this is the case, then interference effects should occur not only in high-interference sentences, but also in low-interference sentences. This is consistent with the findings of Van Dyke and McElree (2006), among others (e.g., Gordon, Hendrick & Levine, 2002; Fedorenko, Gibson & Rohde, 2006), who showed that extra-sentential verbal material in memory interfered with sentence processing. Alternatively, an overall effect of performance on the Brown-Peterson task, or on any other supplementary task, may be driven by processes that are not specific to language processing, such as maintenance of task-related goals and attention to the task, since participants with better performance on supplementary tasks may be expected to be more attentive. The critical test for whether performance on supplementary tasks relates to sentence processing is its interaction with sentence type (Caplan & Waters, 1999). Interestingly, such an interaction was found in reading times at the critical region of relative clauses, wherein the relationship between performance on the Brown-Peterson task and reading times was greater for OR. This result suggests that resistance to interference is involved in processing of relative clauses and that it is more relevant for processing of OR than SR. This is in line with the cue-based parsing account, which predicts that resistance to interference should impact sentence processing as a function of retrieval interference (which is assumed to be higher in OR than in SR) .

Better performance on the vocabulary subtest of WAIS-III, indexing larger verbal knowledge, was associated with shorter reading times at the critical region of relative clauses particularly for SR. This result departed from previous results showing a role of verbal knowledge in interference resolution in sentence processing: Both Van Dyke, Johns and Kukona (2014) and Tan, Martin and Van Dyke (2017) found a stronger impact of verbal knowledge on the sentences in which interference was higher, although the direction of the effects differed. Here, we found instead that verbal knowledge had a stronger impact on processing of the sentences where interference is expected to be lower (SR), contrary to what would be predicted by the cue-based parsing account. Although our finding is suggestive of a role of verbal knowledge in relative clause processing, the processes responsible for this effect remain to be clarified.

Better performance on Reading Span, which was considered a proxy for higher working memory capacity, was associated with higher accuracy for relative clauses, replicating previous research (e.g., Caplan and Waters, 1999), and higher accuracy for control structures. These overall main effects presumably reflect a general role of working memory capacity on sentence processing. Better performance on Reading Span was also associated with higher reading times of sentences containing relative clauses at the post-critical region. This result was unexpected. It may be that participants with higher working memory capacity processed sentences with relative clauses more deeply, contributing to their larger accuracy. Interestingly, Reading Span also interacted with relative clause type and control type. Concerning relative clauses, better performance on Reading Span was correlated with shorter response times especially for OR, in accordance with (i) the Dependency Locality Theory, which predicts that working memory capacity should be more relevant for sentences that are more resource demanding (i.e., OR); (ii) and Friedmann, Belleti & Rizzi's (2009) minimality account, which proposes that working memory capacity should be especially relevant for processing of OR, due to a computationally demanding configuration of featural intervention. However, better performance on Reading Span was associated with shorter reading times at the critical region especially for SR. This result was unexpected, and it is inconsistent with both the Dependency Locality Theory and Friedmann Belleti & Rizzi's (2009) Minimality account, since under no circumstances are SR expected to be more demanding in terms of memory resources. It suggests that participants with larger working memory capacities read easier sentences faster, and does not inform about the role of working memory abilities in reading harder sentences. As for control, better performance on Reading Span was correlated with higher response accuracy especially for OC, although the effect was only marginally significant, limiting our conclusions. Although not anticipated, Boland and colleagues' (1990) suggestion may help explain this result: since OC involves a semantically more complex event structure, WMC could be more relevant for OC processing. Future research should explore this possibility in depth.

The results of the full models suggest that general psychological processes of resistance to interference, lexical knowledge and working memory capacity modulate certain processes involved in tasks assessing syntactic processing, contra claims of modularity (Caplan & Waters, 1999). Our data support the hypothesis that resistance to interference benefits parsing by allowing the parser to be less affected by competitors in cue-based retrieval, as proposed by the cue-based parsing account. However, the roles of lexical knowledge and working memory capacity on syntactic processing are not clear, given that the observed results were not consistent with the main accounts.

Furthermore, the results of the full models align with the results of the simple models in suggesting that relative clauses and control structures are distinct mental phenomena: whereas relative clause processing interacted with resistance to interference, verbal knowledge and working memory capacity, control processing interacted only with working memory capacity.

4.3. Locus of complexity effects of object relatives

Taken together, the results obtained with the simple models suggest that OR are harder to process than SR, whereas SC is not harder to process than OC. This suggests that the complexity of OR is not primarily due to grammar-independent memory constraints (Gibson, 2000; Lewis, Vasishth & Van Dyke, 2006). Instead, it is consistent with the proposal that the complexity of OR results from featural intervention in the movement dependency, either due to memory overload (Friedmann, Belleti & Rizzi, 2009) or failure to activate relevant features (Costa, Grillo & Lobo, 2013). The results from the full models were more complicated, but we believe that they allow for a more detailed characterization of complexity effects of OR.

Although we found evidence for a role of general resistance to interference, verbal knowledge and general working memory capacity in relative clause processing, we did not find a modulatory effect of supplementary tasks in OR complexity effects (i.e., more difficulty for OR than for SR in the sentence comprehension task) in regards to accuracy and reading times (at the spillover region), which is in line with previous work (e.g. Caplan & Waters, 1999; James, Fraundorf, Lee & Watson, 2018). A modulatory effect of Reading Span on OR complexity effect emerged, instead, in response times to the comprehension probe. As far as we know, response times have not been previously assessed in studies of individual differences in relative clause processing. We speculate that this measure may reflect processes different from those indexed by accuracy and reading times. Whereas complexity effects of OR surfacing in accuracy and reading times may depend on a syntax-specific, functionally isolated process, complexity effects surfacing in response times may depend on more general processes, such as working memory capacity. We will close this section proposing a possible explanation.

Our results suggest that it is plausible that the complexity of OR is primarily due to featural intervention in the movement dependency, which renders the construction of an OR representation difficult, inducing a cost in reading times and often causing processing breakdown, lowering accuracy. Reading times and accuracy may therefore be expected to directly reflect problems with featural intervention, which may depend on a functionally isolated system. If these assumptions are held, the lack of correlation between complexity effects of OR in accuracy and reading times and supplementary tasks is predicted. Response times, on the other hand, may be sensibly expected to reflect access to a previously correctly encoded/constructed sentence representation, since they were only analyzed for correct trials. If so, we may assume that longer response times for OR than for SR in the sentence comprehension task are due to poorer encoding of OR representations (perhaps due to intervention), and modulatory effects of working memory capacity on OR complexity effects surfacing in response times may be expected, since the poorer representations of OR should be harder to retrieve, rendering maintenance in working memory especially important.

4.4. Significance and limitations of the present study

We explored the empirical adequacy of three models of syntactic complexity: the Dependency Locality Theory, the cue-based parsing account and the minimality account, by comparing processing of relative clauses with processing of control structures (both across individuals and in terms of individual differences). Taken together, our results support the minimality approach to relative clause complexity effects, assuming a non-movement analysis of control, since complexity effects parallel to those found for OR are expected only for structures involving (hierarchical) intervention in movement dependencies.

If this picture is correct, then the widespread use of data from processing of relative clauses to inform general models of sentence complexity (e.g., based on general principles of memory) may be inappropriate (e.g., the infamous double center-embeddings presented in section 1.3.1). The reason for this is that, if the minimality account is correct, relative clauses are special structures, in that their complexity results primarily from specific grammatical principles, and not from their surface configuration. More generally, these conclusions speak to the need for a closer dialogue between grammatical and processing models of sentence processing. The interaction should be beneficial in both directions: (i) On the one hand, some processing contrasts of complexity may only be adequately explained by postulating different grammatical representations of the structures contrasted - in our view, this is the case of the contrast between relative clauses and control structures; (ii) On the other hand, competition between equally plausible grammatical analyses for a given structure type may be settled by processing data. We believe that the case of control illustrates this latter point: accepting the minimality account of complexity of relatives, which we believe is the account that best fits our data, we necessarily conclude that control is not movement.

Our results suggest that the system responsible for syntactic analysis is not, as a whole, functionally isolated. Resistance to interference, working memory capacity and verbal knowledge modulated different aspects of syntactic processing. Investigation of individual differences in sentence processing is therefore valuable, since it may inform theory-building. Nevertheless, some processes, such as those related to featural intervention, may be syntax-specific and cognitively isolated, and may not draw on more general cognitive resources, as suggested by our data. From this perspective, it is not surprising that Caplan and Waters (1999), among others (Caplan & Waters, 2005; Caplan, DeDe, Waters, Michaud & Tripodis, 2011; James, Fraundorf, Lee & Watson, 2018) consistently failed to find interactions between OR complexity effects and performance on external tasks (cf. Gordon, Hendrick & Levine, 2002; Fedorenko, Gibson & Rhode, 2006). This conclusion is in line with research showing that the strength of island effects (in acceptability data) is not modulated by working memory capacity, further suggesting that grammatical constraints associated with locality depend on cognitively isolated processes (Sprouse, Wagers & Phillips, 2012).

An interesting question on constraints on movement concerns their origin. Why is it that syntactic dependencies are generally not held between two dependent elements across a structurally similar third element? Ortega-Santos (2011) proposed that RM should be seen as a grammaticized response to memory. More specifically, it is proposed that the parsing system functions according to the principles proposed by cue-based parsing models and that RM emerges as a way of limiting sentence complexity, by blocking potential configurations expected to cause memory interference. This is an attractive perspective, because the pernicious character of "similarity" in RM is assumed to result from more general principles of memory similarity-interference, explaining why similarity-related problems arise both in grammar and processing. Abstract notions of "economy" and "efficiency" (Chomsky, 2005) may, thus, be grounded in well-established principles of memory functioning. Although our results suggest that the cue-based parsing perspective of complexity in syntactic processing is incomplete, the significant interaction between relative clause type and resistance to interference in reading times, together with the studies reviewed in section 1.4.1, and many more, suggest that interference susceptibility is indeed a property of the parsing system, rendering Ortega Santo's view plausible. If this view is on the right track, our results indicate that the robust complexity effects of OR may in fact be caused by the very system whose function is to reduce complexity.

Before proceeding to the conclusion, we would like to discuss some limitations of our work, concerning the choice of supplementary tasks. On the one hand, cognitive tasks are not process pure, which means that each task measures several processes, only some of which may actually be related to the construct of interest. On the other hand, the same construct of interest may be measured by many different tasks. This suggests that significant interactions with a supplementary task may not be due to the construct of interest that is assumed to be measured, and it also means that alternative tasks, with greater validity, could have been used to measure the constructs of interest. To give a concrete example, working memory capacity, as measured by Reading Span tasks and related tasks (operation span, symmetry span, etc) has been shown to involve processes of resistance to interference and attention (Kane & Engle, 2000; Engle & Kane, 2004; Bunting, 2006, Unsworth, 2010, Unsworth, Fukuda, Awh, Vogel, 2014), leading Engle and colleagues (e.g. Engle & Kane, 2004) to propose that working memory capacity includes a component of executive attention responsible for maintaining task goals activated under conditions of interference and competition, which has been taken to be responsible for correlations between working memory tasks and other complex tasks (e.g IQ tasks, Bunting, 2006). If we accept that working memory capacity tasks indeed measure a multifaceted construct, interpreting effects of working memory in terms of capacity may not be entirely accurate. Along the same lines, one may argue whether our choice of the fluency task as a measure of lexical access ability was adequate. It is possible that other tasks of lexical access, such as lexical decision tasks, provided a more direct measure of efficiency of access to the lexicon. These are pervasive problems in individual differences research. In sum, firm conclusions based on our results are limited by the number and nature of the tasks assessed. Future research could test whether the results obtained here can be replicated with other supplementary tasks assumed to measure the same constructs.

We would also like to note that even though we focused on memory and grammatical explanations of sentence complexity, there are alternatives, especially concerning complexity effects of OR, such as reanalysis theories (Traxler, Morris & Seely, 2002; Traxler, Williams, Blozis & Morris, 2005), discourse-based theories (Mak, Vonk, Schriefers, 2008) and experience/frequency-based theories (Reali & Christiansen, 2007) (see Gordon & Lowder, 2012 for a review). Though each of these accounts may have some validity, none of them can completely explain why manipulations of similarity significantly modulate OR complexity (e.g. Gordon, Hendrick & Johnson, 2001), suggesting that even if minimality is not sufficient to explain the processing cost of OR, it is nevertheless necessary.

There is, however, one alternative account based on similarity-interference which we have not considered – the account of Gordon, Hendrick & Johnson (2001). In their view, the subject and object of the relative clause are not maintained in memory, but stored and, subsequently, retrieved at the embedded verb site for thematic-role assignment. Importantly, it is proposed that when both constituents are similar enough, they are confused in memory, and information about order of occurrence, assumed to be critical for identifying which constituent is the subject and which is the object, is lost, hampering comprehension. This account dissociates relative clauses and control, since in control only one noun needs to be retrieved and order information is less relevant (since correct interpretation is determined by verb meaning).

There are at least two unattractive aspects in Gordon, Hendrick and Johnson's (2001) account: (i) the assumption that the embedded subject needs to be retrieved for an adjacent integration with the embedded verb is dubious (see McElree, Foraker & Dyer 2003); (ii) the assumption that order information is used in sentence processing is inconsistent with recent research indicating the contrary (McElree, Foraker & Dyer, 2003, Shvartsman & Van Dyke, 2018). For these reasons, we believe that it is not a viable alternative to the accounts presented here.

5. Conclusion

Our study shows that OR reveal complexity effects not paralleled by SC, suggesting that (i) featural intervention, and not memory decay or interference, is primarily responsible for OR processing difficulty; (ii) control is not movement, contra recent proposals. Furthermore, our study suggests that syntactic processing may involve both domain-general as well as domain-specific processes, and that questioning in general terms whether the system for syntactic parsing is functionally isolated or not may not be appropriate – it might be that certain processes in (syntactic) parsing are isolated, but some other processes interact with domain-general processes.

This work provides further support for Grillo's (2009) Generalized Minimality approach. This approach allows us to weave an integrated account of island constraints, canonicity effects, delays in acquisition and processing complexity in adults, and provides fertile grounds for a more intimate cooperation between theoretical and experimental linguists, making it desirable in Cognitive Science research.

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APPENDICES

Appendix I: Experimental sets used in the sentence comprehension task

(a – SR; b – OR; c – SC; d – OC)

1. a. O político que ofendeu o barbeiro escalou a montanha
   b. O político que o barbeiro ofendeu escalou a montanha
   c. O político jurou ao barbeiro escalar a montanha
   d. O político encorajou o barbeiro a escalar a montanha

2. a. O linguista que salvou o palhaço vendeu os quadros
   b. O linguista que o palhaço salvou vendeu os quadros
   c. O linguista jurou ao palhaço vender os quadros
   d. O linguista encorajou o palhaço a vender os quadros

3. a. A historiadora que confrontou a artista rejeitou a oferta
   b. A historiadora que a artista confrontou rejeitou a oferta
   c. A historiadora jurou à artista rejeitar a oferta
   d. A historiadora encorajou a artista a rejeitar a oferta

4. a. O canalizador que agrediu o motorista visitou o palácio
   b. O canalizador que o motorista agrediu visitou o palácio
   c. O canalizador jurou ao motorista visitar o palácio
   d. O canalizador encorajou o motorista a visitar o palácio

5. a. A tradutora que reconheceu a analista desenhou o logotipo
   b. A tradutora que a analista reconheceu desenhou o logotipo
   c. A tradutora jurou à analista desenhar o logotipo
   d. A tradutora encorajou a analista a desenhar o logotipo

6. a. O informático que assustou o físico apresentou o espetáculo
   b. O informático que o físico assustou apresentou o espetáculo
   c. O informático jurou ao físico apresentar o espetáculo
   d. O informático encorajou o físico a apresentar o espetáculo

7. a. O bailarino que divertiu o repórter cozinhou o bife

b. O bailarino que o repórter divertiu cozinhou o bife
c. O bailarino assegurou ao repórter cozinhar o bife
d. O bailarino obrigou o repórter a cozinhar o bife

8. a. O guitarrista que inspirou o jogador procurou o artigo
b. O guitarrista que o jogador inspirou procurou o artigo
c. O guitarrista assegurou ao jogador procurar o artigo
d. O guitarrista obrigou o jogador a procurar o artigo

9. a. A psicóloga que chamou a estilista imprimiu os documentos
b. A psicóloga que a estilista chamou imprimiu os documentos
c. A psicóloga assegurou à estilista imprimir os documentos
d. A psicóloga obrigou a estilista a imprimir os documentos

10. a. O eletricista que abraçou o carteiro recolheu as assinaturas
b. O eletricista que o carteiro abraçou recolheu as assinaturas
c. O eletricista assegurou ao carteiro recolher as assinaturas
d. O eletricista obrigou o carteiro a recolher as assinaturas

11. a. A cientista que protegeu a escritora planeou a viagem
b. A cientista que a escritora protegeu planeou a viagem
c. A cientista assegurou à escritora planear a viagem
d. A cientista obrigou a escritora a planear a viagem

12. a. O engenheiro que irritou o treinador enviou a mensagem
b. O engenheiro que o treinador irritou enviou a mensagem
c. O engenheiro assegurou ao treinador enviar a mensagem
d. O engenheiro obrigou o treinador a enviar a mensagem

13. a. O matemático que chateou o bombeiro escondeu o presente
b. O matemático que o bombeiro chateou escondeu o presente
c. O matemático ameaçou o bombeiro de esconder o presente
d. O matemático autorizou o bombeiro a esconder o presente

14. a. A violinista que confortou a médica abandonou o grupo

b. A violinista que a médica confortou abandonou o grupo
c. A violinista ameaçou a médica de abandonar o grupo
d. A violinista autorizou a médica a abandonar o grupo

15. a. A atriz que corrigiu a ciclista trancou a porta
b. A atriz que a ciclista corrigiu trancou a porta
c. A atriz ameaçou a ciclista de trancar a porta
d. A atriz autorizou a ciclista a trancar a porta

16. a. A veterinária que atacou a educadora contactou as finanças
b. A veterinária que a educadora atacou contactou as finanças
c. A veterinária ameaçou a educadora de contactar as finanças
d. A veterinária autorizou a educadora a contactar as finanças

17. a. A cabeleireira que motivou a dentista apagou os ficheiros
b. A cabeleireira que a dentista motivou apagou os ficheiros
c. A cabeleireira ameaçou a dentista de apagar os ficheiros
d. A cabeleireira autorizou a dentista a apagar os ficheiros

18. a. A jornalista que perdoou a terapeuta partiu o copo
b. A jornalista que a terapeuta perdoou partiu o copo
c. A jornalista ameaçou a terapeuta de partir o copo
d. A jornalista autorizou a terapeuta a partir o copo

19. a. A agricultora que consolou a bióloga vestiu o casaco
b. A agricultora que a bióloga consolou vestiu o casaco
c. A agricultora garantiu à bióloga vestir o casaco
d. A agricultora forçou a bióloga a vestir o casaco

20. a. O poeta que distraiu o geólogo atendeu o telefone
b. O poeta que o geólogo distraiu atendeu o telefone
c. O poeta garantiu ao geólogo atender o telefone
d. O poeta forçou o geólogo a atender o telefone

21. a. A socióloga que socorreu a gestora gravou a reportagem

b. A socióloga que a gestora socorreu gravou a reportagem
c. A socióloga garantiu à gestora gravar a reportagem
d. A socióloga forçou a gestora a gravar a reportagem

22. a. A freira que perseguiu a porteira terminou o projeto
b. A freira que a porteira perseguiu terminou o projeto
c. A freira garantiu à porteira terminar o projeto
d. A freira forçou a porteira a terminar o projeto

23. a. O mágico que elogiou o alfaiate concluiu o curso
b. O mágico que o alfaiate elogiou concluiu o curso
c. O mágico garantiu ao alfaiate concluir o curso
d. O mágico forçou o alfaiate a concluir o curso

24. a. O arquiteto que enganou o economista assistiu à conferência
b. O arquiteto que o economista enganou assistiu à conferência
c. O arquiteto garantiu ao economista assistir à conferência
d. O arquiteto forçou o economista a assistir à conferência

25. a. O músico que criticou o pintor escreveu um livro
b. O músico que o pintor criticou escreveu um livro
c. O músico prometeu ao pintor escrever um livro
d. O músico convenceu o pintor a escrever um livro

26. a. A fotógrafa que emocionou a detetive cumpriu o prazo
b. A fotógrafa que a detetive emocionou cumpriu o prazo
c. A fotógrafa prometeu à detetive cumprir o prazo
d. A fotógrafa convenceu a detetive a cumprir o prazo

27. a. A banqueira que empurrou a cantora construiu um puzzle
b. A banqueira que a cantora empurrou construiu um puzzle
c. A banqueira prometeu à cantora construir um puzzle
d. A banqueira convenceu a cantora a construir um puzzle

28. a. O professor que ignorou o taxista recebeu os convidados

b. O professor que o taxista ignorou recebeu os convidados
c. O professor prometeu ao taxista receber os convidados
d. O professor convenceu o taxista a receber os convidados

29. a. A investigadora que acalmou a advogada preparou a festa
b. A investigadora que a advogada acalmou preparou a festa
c. A investigadora prometeu à advogada preparar a festa
d. A investigadora convenceu a advogada a preparar a festa

30. a. O comediante que insultou o mecânico assumiu a culpa
b. O comediante que o mecânico insultou assumiu a culpa
c. O comediante prometeu ao mecânico assumir a culpa
d. O comediante convenceu o mecânico a assumir a culpa

Appendix II: Lists of words used in the Brown-Peterson task

Mammals			
PI build-up list	PI build-up list	PI build-up list	Release from PI List
CABRA	GIRAFA	LEOPARDO	CHAPÉU
BURRO	FOCA	OVELHA	BLUSÃO
URSO	CHIMPANZÉ	LOBO	SAPATILHAS
HIPOPÓTAMO	ZEBRA	CAMELO	COLETE
LINCE	CANGURU	GORILA	CINTO
VEADO	RAPOSA	TOURO	LAÇO
HIENA	BÚFALO	PUMA	PIJAMA
GAZELA	JAGUAR	LEBRE	ROUPÃO

Countries			
PI build-up list	PI build-up list	PI build-up list	Release from PI List
GRÉCIA	CHINA	NORUEGA	MARACUJÁ
ANGOLA	DINAMARCA	CANADÁ	MELANCIA
MOÇAMBIQUE	ÁUSTRIA	IRLANDA	NÊSPERA
RÚSSIA	MÉXICO	ARGENTINA	AMORA
POLÓNIA	ÍNDIA	LÍBIA	COCO
IRÃO	MARROCOS	PERU	TORANJA
URUGUAI	TURQUIA	EGITO	LIMA
ISRAEL	ESCÓCIA	IRAQUE	PAPAIA

Human body parts			
PI build-up list	PI build-up list	PI build-up list	Release from PI List
BARRIGA	FÍGADO	PEITO	PALÁCIO
JOELHO	COSTAS	CABELO	CHALÉ
ANCA	CÉREBRO	INTESTINO	CARAVANA
TORNOZELO	PULMÃO	RIM	PENSÃO
LÍNGUA	COTOVELO	ESÓFAGO	DUPLEX
CRÂNIO	TESTA	FARINGE	MOTEL
PÂNCREAS	UMBIGO	BEXIGA	POUSADA
LARINGE	PESTANA	QUEIXO	QUARTEL

Appendix III: Materials used in the Reading Span task

Set 1

O António quer aprender a tocar piano, mas não sabe como começar. ? B

O Pedro saltou para a cama, que se partiu devido ao impacto. ? J

Set2

As pedras caíam-lhe dos olhos enquanto fazia um esforço para se manter de pé. ? F

O menino finalmente largou o sapo que encontrou junto ao riacho. ? H

Ficou tão desapontado com o filme que jurou nunca mais ir ao cinema. ? L

Se tivesse obedecido à almofada, não tinha magoado os joelhos. ? R

A biologia caiu numa noite de Inverno, causando o pânico entre os vizinhos. ? Q

Set3

O terramoto assustou a população, mas não causou danos materiais significativos. ? X

Se a criança vir o filme com os extraterrestres, não vai conduzir de noite. ? M

Set4

O casal levou a filha e os dois cães ao parque quando nevou. ? R

Enquanto fritávamos as batatas, íamos cozendo o filme que passava na televisão. ? F

Sempre que passava férias em casa dos avós, o Fernando engordava cinco quilos. ? H

Set5

O Alberto foi a casa da vizinha pedir pimenta para o guisado. ? L

O João e o Tiago compraram uma consola durante a época de exames. ? B

Gostava de saber assar latim, mas faltava-lhe a dedicação para aprender. ? J

Pelo menos uma vez por hora, a família reúne-se para jantar. ? M

Set6

O jogo estava quase a terminar quando ele marcou um golo de cabeça. ? Q

O estudante contemplou entusiasticamente a dedução lógica do cão Alemão. ? X

O Manuel cheira a água porque foi ao bar jogar snooker. ? B

Foram expulsos da exposição sobre a Grécia Clássica por tirarem pinturas com flash. ? F

Quando foi apanhada a fumar pelo pai, a Marta sentiu-se envergonhada. ? M

Set7

Deviam ter ido ao céu, ainda que não tivessem estudado. ? Q

No momento em que entrou na cidade, o Luís arrependeu-se de ter mergulhado. ? J

Os dedos doíam-lhe, e estava com sono, mas tinha de terminar o desgosto. ? L

Ficaram tão comovidos com o gatinho que acabaram por ficar com ele. ? H

Set8

Quando entrou em casa, a Joana tropeçou nos sapatos do pai. ? R

A velhota nunca usava o telemóvel, ou por teimosia, ou porque não sabia. ? X

O canivete interrompeu o discurso, furioso, e repreendeu o público. ? L

Quando viviam no campo, tinham uma horta com uma grande variedade de legumes. ? M

O mestrado parou junto ao miradouro de onde se consegue ver o lago. ? F

Set9

Quando viveu no deserto, sentiu uma ligação espiritual com o mundo. ? X

A Luísa fica nervosa sempre que fala ao telefone com os tios. ? B

Set10

Serviu um copo de vinho e sentou-se à lareira, a ler um livro. ? R

Quando foi à fazenda dos avós, a menina apanhou uma flor para a mãe. ? J

Viajaram até ao Alentejo só para comerem açorda de computador. ? Q

Set11

Todos foram convidados para a festa menos ela, porque era diferente. ? H

A camisola branca fica-lhe larga, mas a preta fica-lhe provável. ? M

Quando viu a sanidade no quintal, o rapaz foi buscar a máquina fotográfica. ? L

Os jovens plantaram uma árvore em memória do amigo que sobreviveu no atentado. ? F

Set12

Quando dormiram a ver os filmes da Disney, sentiram-se nostálgicos. ? R

O rato filosofou sorrateiramente na despensa e roubou o maior queijo que encontrou. ? B

O pirata ordenou à tripulação que recolhesse a âncora do navio roubado. ? H